EPA/540/R-94/529
August 1995

SUBSURFACE VOLATILIZATION AND VENTILATION SYSTEM (SVVS)

INNOVATIVE TECHNOLOGY EVALUATION REPORT

Design by Billings and Associates, Inc.
Installation by Billings and Associates, Inc. and Brown & Root Environmental
Operated by Brown & Root Environmental

NATIONAL RISK MANAGEMENT RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

NOTICE

The information in this document has been prepared for the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) Program under Contract No. 68-CO-0048. This document is draft and will be subjected to the EPA's peer and administrative reviews prior to approval for publication as an EPA document. Mention of trade names of commercial products does not constitute an endorsement or recommendation for use.

FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

ACRONYMS, ABBREVIATIONS AND SYMBOLS

μg	Microgram
$\mu g/kg$	Micrograms per kilogram
$\mu g/l$	Micrograms per liter
A0	Administrative Order
AQCR	Air Quality Control Regions
AQMD	Air Quality Management District
ARAR	Applicable or relevant and appropriate requirement
ATTIC	Alternative Treatment Technology Information Center
BAI	Billings and Associates, Inc.
BEC	Biological Emission Control
B&RE	Brown & Root Environmental
BTEX	Benzene, toluene, ethylbenzene, and
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERI	Center for Environmental Research Information
cfm	Cubic feet per minute
CFR	Code of Federal Regulations
CO_2	Carbon Dioxide
CWA	Clean Water Act
DCE	Dichloroethene
DNAPLs	Dense non-aqueous phase liquids
DNR	Department of Natural Resources
dscfm	Dry standard cubic feet per minute

ACRONYMS, ABBREVIATIONS AND SYMBOLS (Continued)

EIT	Environmental Improvement Technologies
EPA	U.S. Environmental Protection Agency
ESD	Explanation of Significant Difference
EV	Electra-Voice, Inc.
FS	Feasibility Study
ITER	Innovative Technology Evaluation Report
kg	Kilogram
kW	Kilowatt
kWh	Kilowatt-hour
MCL	Maximum contaminant levels
MCLG	Maximum contaminant level goals
mg/kg	Milligrams per kilogram
mg/l	Milligrams per liter
NAAQS	National Ambient Air Quality Standards
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NPDES	National Pollutant Discharge Elimination System
NTIS	National Technical Information Service
ORD	EPA Office of Research and Development
OSHA	Occupational Safety and Health Act
OSWER	Office of Solid Waste and Emergency Response
O U	Operable Unit
PCB	Polychlorinated biphenyl
PCE	Tetrachloroethene

ACRONYMS, ABBREVIATIONS AND SYMBOLS (Continued)

POTW	Publicly-owned treatment works
PPE	Personal protective equipment
PSD	Particle size distribution
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
ROD	Record of Decision
RREL	Risk Reduction Engineering Laboratory
S.U.	Standard Units
SAIC	Science Applications International Corporation
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SITE	Superfund Innovative Technology Evaluation
SVE	Soil-Vapor Extraction
SVVS	Subsurface Volatilization and Ventilation System
SWDA	Solid Waste Disposal Act
TC	Total Carbon
TCE	Trichloroethene
TER	Technology Evaluation Report
THC	Total Hydrocarbons
TIC	Total Inorganic Carbon
TKN	Total Kjeldahl Nitrogen
TSCA	Toxic Substances Control Act
UST	Underground Storage Tank

ACRONYMS, ABBREVIATIONS AND SYMBOLS (Continued)

VCU	Vapor Control Unit
VISITT	Vendor Information System for hnovative Treatment Technologies
VOC	Volatile Organic Compound
yd^3	Cubic yards

ACKNOWLEDGEMENTS

This report was developed under the direction of Mr. John Martin, the EPA Technical Project Manager for this SITE Demonstration at the Risk Reduction Engineering Laboratory (RREL) in Cincinnati, Ohio. Prior to Mr. Martin project direction and coordination was provided by Ms. Kim Kreiton, formerly with the USEPA-RREL.

This report was prepared by the Environmental Technology Division of Science Applications International Corporation (SAIC), Hackensack, New Jersey under the direction of Mr. John J. Ring, the SAIC Work Assignment Manager, for the U.S. Environmental Protection Agency under Contract No. 68-CO-0048. This report was written in large part by Dr. Scott Beckman and Mr. Omer Kitaplioglu. Statistical analyses and the experimental design were developed by Al Unger and Dan Patel. Project Quality Assurance was provided by Ray Martrano and Rita Stasik. Field management responsibilities were shared between Mike Bolen and Andy Matuson. Field geologist responsibilities were conducted by Paul Feinberg. Field health and safety coordination was provided by Brandon Phillips.

The cooperation and participation of Mr. Timothy Mayotte, Mr. Steve Thompson and supporting staff of Brown & Root Environmental throughout the course of the project and in review of this report are gratefully acknowledged.

Ms. Beth Reiner and Ms. Eugenia Chow, the Remedial Project Managers of USEPA's Region V provided invaluable assistance and guidance in initiating the project and in interpreting and responding to regulatory needs.

Special thanks are offered to Mr. Ronald Graham and the employees of Electra-Voice for their hospitality and assistance throughout this SITE Demonstration.

EXECUTIVE SUMMARY

This report summarizes the findings associated with a Demonstration Test of Environmental Improvement Technologies' (EIT) Subsurface Volatilization and Ventilation System (SVVS) process. The technology was evaluated under the EPA Superfund Innovative Technology Evaluation (SITE) Program in conjunction with an independent one-year testing of the technology to provide justification for the execution of an Explanation of Significant Difference (ESD) to the Record of Decision (ROD) for Operable Unit (OU) Number One. Under the SITE Program, the technology was evaluated to determine its effectiveness in reducing volatile organic contamination in the vadose zone of the former "dry well area" of the Electra-Voice facility after one year of treatment. The technology was evaluated against the nine criteria for decision-making in the Superfund Feasibility Study process. The results of this evaluation are presented in Table ES- 1.

The SVVS process is an integrated technology that utilizes the benefits of soil vapor extraction/air sparging and in-situ bioremediation for the treatment of subsurface organic contamination in soil and groundwater. The SVVS process evaluated under the USEPA SITE Program was developed and designed by Billings and Associates, Inc. (BAI) and operated by Brown & Root Environmental (B&RE) (formerly Halliburton NUS Environmental Corporation) (For the purposes of this report, BAI and B&RE are referred to as the developer and operator, respectfully). The SVVS process uses vapor extraction to remove the easily-strippable volatile components and biostimulation to remove the less volatile more tightly sorbed components. Vapor extraction appears to be the more dominant removal mechanism during the early phases of treatment, while biostimulation processes dominate in later phases. During the early stages of system application, when vapor extraction is the dominant treatment mechanism, the extracted vapors might need to be treated above ground before release to the atmosphere. During this period, which can last anywhere from two weeks to a few months, the developer claims that system off-gasses can be treated by BAI's Biological Emission Control (BEC) biofilters, alone or in combination with conventional activated carbon or other mechanisms for additional air polishing. The developer claims that remediation using the combination of vapor extraction and biostimulation is more rapid than the use of biostimulation alone, while generating lower quantities of volatile organic emissions than vapor extraction technologies. In addition, the SVVS can remediate contaminants that would not be remediated by vapor extraction alone (chemicals with lower volatilities and /or chemicals that are tightly sorbed). These benefits translate into lower costs and faster remediations.

TABLE ES-1 EVALUATION CRITERIA FOR THE ENVIRONMENTAL IMPROVEMENT TECHNOLOGIES, INC. SVVS VAPOR EXTRACTION/AIR SPARGING AND IN-SITU BIOREMEDIATION TECHNOLOGY

OVERALL PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT	COMPLIANCE WITH FEDERAL ARARs	LONG TERM EFFECTIVENESS AND PERMANENCE	REDUCTION OF TOXICITY, MOBILITY, OR VOLUME THROUGH TREATMENT
Protects human health and the environment by removing and destroying organic contaminants from liquid, aqueous, sorbed, and vapor phases in soil and groundwater.	Requires compliance with RCRA treatment, storage, and disposal regulations (if hazardous wastes are present).	Effectively destroys or removes organic contamination from affected matrix.	Significantly reduces the toxicity of organic contaminants as biodegradation converts contaminants to non-toxic by-products (CO, and H_2O).
Remediation can be performed in-situ, reducing the need for excavation.	Operation of on-site treatment system may require compliance with location-specific ARARs.		Volume of contaminants is significantly reduced as contaminants are removed by vapor extraction and biodegraded by indigenous microbes
Off-gas treatment system reduces airborne emissions. Air emissions can be favorably controlled within regulatory limits by adjusting the rate of air injection and extraction.	Minimal wastewater discharges to POTWs may require pre-treatment to comply with the Clean Water Act or Safe Drinking Water Act, depending on the contaminant.		Off-gas treatment system is used initially to reduce emissions, until biodegradation rate exceeds rate of contaminant mass transfer to the vapor phase.
Technology is primarily suited to remove and destroy subsurface organic contaminants. Can be used to treat heavy metals in groundwater by raismg redox potential and inducing metals to precipitate.	Emission control may be needed to ensure compliance with air quality standards depending upon local ARARs.		Some treatment residues (drill cuttings, decontamination water, condensate, spent activated carbon and personal protective equipment) might require special disposal requirements. Condensate can be used as make-up water for the BEC units.

SHORT TERM EFFECTIVENESS	IMPLEMENTABILITY	COST	COMMUNITY ACCEPTANCE	STATE ACCEPTANCE
Treatment of a site using SVVS removes and destroys subsurface organic contaminants.	Hardware components used to construct and operate the SVVS are common and readily available.	The cost for remediation, assuming that no off-gas treatment is necessary, is $10.36/yd^3$.	Minimal short-term risks to the community make this technology appealing to the public.	State ARARs may be more stringent than federal regulations.
Presents potential short-term chemical exposure risks to workers installing a system due to the potential for fugitive emissions being generated during excavation and construction.	Utility needs are minor (electricity, water and sewer, if possible).	Site preparation is the most significant cost associated with SVVS representing 28% of the overall cost. Residuals handling and disposal and analytical services are the next largest cost component.	Technology is generally accepted by the public because it provides a permanent solution.	State acceptance of the technology varies depending upon ARARs.
Depending on the volatility and biodegradability of organic contaminants, the highest mass removal rates can be experienced at the beginning of treatment.	The SVVS is installed in-place and is custom- designed for a site. An average system can take up to a month to install before being ready to operate. The technology is not considered mobile.	Labor accounts for a relatively small percentage of the overall cost (9%).	Noise generated during system installation could be troublesome, but once the system is operational, it does not generate much appreciable noise.	Each SVVS system is site-specific, and can be designed to meet state criteria.
Some short-term risks associated with vacuum extraction off-gas emissions might exist during the early stages of treatment when the rate of vapor extraction exceeds the rate of biodegradation. Depending on site requirements, the risks can be reduced by an emission treatment system.	Support equipment during system installation includes drill rigs, trenchers, and possibly backhoes, front-end loaders and fork lifts.	If off-gas polishing is required, above-ground air treatment costs could account for 43% of the total cleanup cost, depending on the air treatment train selected.		

SHORT TERM EFFECTIVENESS	IMPLEMENTABILITY	COST	COMMUNITY ACCEPTANCE	STATE ACCEPTANCE
	A site's physical and chemical conditions must be adequately defined to optimize system design and installation.	The cost for system expansion is typically no more than 10-20% of total cleanup cost due to the simplicity of system construction and reserved capacity of vacuum and injection pumps.		
	The technology is not recommended for remediation of materials of very low permeability.			

Actual cost **of a remedial technology is site-specific and is dependent on factors such as the cleanup level, contaminant concentrations and types, waste characteristics, and volume necessary for treatment. Cost data presented in this table are for treating 2 1,300 yd^3 of soil.**

The SVVS technology was tested at the Electra-Voice, Inc. site in Buchanan, Michigan to assess the developer's claim that the system would reduce the average contamination of seven target contaminants in the vadose zone by 30% after one year of system operation. This became the critical objective of the SITE Demonstration. The one-year time frame was chosen for testing purposes only, and does not reflect the limits of the technology. The technology was evaluated for a number of secondary objectives all of which are discussed in this Innovative Technology Evaluation Report.

CONCLUSIONS BASED ON CRITICAL OBJECTIVE

The SVVS achieved an overall 80.6% reduction in the sum of the seven critical VOCs in the vadose zone after one year of system operation. This level of reduction greatly exceeded the developer's claim which promised a 30% reduction over a one-year time frame. The average concentrations of the sum of the seven critical analytes (benzene, toluene, ethylbenzene, xylenes, trichloroethene, tetrachloroethene, and 1,1-dichloroethene) in the study area before and after one year of operation were 341.5 mg/kg and 66.2 mgikg, respectively. Reductions for each subsurface horizon revealed an 8 1.5% reduction for the "sludge layer", the most contaminated horizon throughout the treatment plot, and 97.8% to 99.8% for all other vadose zone horizons. When evaluating system performance by comparing VOC concentrations in matched boreholes before and after one year of treatment, contaminant reductions ranged from 7 1% to 99%. This indicated that the system operated relatively uniformly over the entire vadose zone of the treatment plot, and no significant untreated areas were encountered, regardless of initial VOC concentration or lithology.

CONCLUSIONS BASED ON SECONDARY OBJECTIVES

The studies conducted by the SITE Program suggest the following conclusions regarding the technology's performance at the Electro-Voice site. These conclusions were based upon secondary project objectives and are presented as follows:

* An analysis of individual VOC contaminants in the vadose zone before and after treatment revealed reductions that ranged from 78% to 92%. Xylenes, the most prevalent compound, comprising 60% of the VOCs in the treatment plot, were reduced by 78% whereas tetrachloroethene, which represented 1.6% of the total VOC concentration in the vadose zone, exhibited a reduction of 92%. The relative distribution of individual compounds in vadose zone soils is similar before and after treatment, suggesting that the technology at this site did not appear to selectively remove or destroy one component over another.

- The technology was evaluated for its ability to reduce VOC contamination in groundwater within the treatment plot. The lack of detectable levels of contamination in the groundwater during system operation precluded any meaningful evaluation of the systems performance on groundwater within the physical boundaries of the treatment plot.

- A comparison of VOC contamination before and after one year of treatment revealed a 99.3% reduction in saturated zone soils. Although no claims were made regarding expected percent reductions in the saturated zone, the reduction that was achieved was comparable to those observed in the vadose zone horizons.

- Soil sampling conducted during Pre-treatment and Post-treatment events did not reveal any compounds present at concentrations that might inhibit biodegradation (i.e., heavy metals). In addition, general soil analyses revealed that there were sufficient quantities of soil nutrients available to biodegrade the entire mass of contamination in the vadose zone of the treatment plot.

- Bimonthly monitoring of the extracted air stream indicates that mass removal rates of VOCs were highest at the beginning of the treatment when soil VOC concentrations were elevated and transfer to the vapor phase occurred easily. As the concentration in the soil decreased, mass removal rates also decreased and stabilized in spite of elevated flow rates. Vapor flow rates observed during the Demonstration fall within the range of conventional SVE systems that rely solely on vapor extraction as the primary mechanism for contaminant removal. The SVVS also exhibited the same pattern observed in conventional SVE systems, which is characterized by high removal rates during the initial operation of the unit, followed by an asymptotic decrease in removal rates.

- The results of three system shut-down tests indicate that biodegradation was occurring across the treatment plot, especially along the southern portion of the treatment plot where the highest levels of soil contamination were measured. The correlation between high biological activity and contaminant occurrence suggests that the technology was able to stimulate biodegradation of contaminants. The results of three shut-down tests suggest a progressive decrease in biological activity over time. The decrease in the rate of biodegradation, however, was significantly less than the rate of decrease of vapor phase contaminants in the vacuum extraction line. This observation would support the developer's claim that biological processes play an increasingly important role, relative to vapor extraction, as the remediation proceeds.

- The performance of the Biological Emission Control (BEC) system could not be evaluated since it was taken off-line a few months into the Demonstration when the exhaust off-gasses met the discharge criteria for the site.

- The system was initially installed and operated in a large portion of the site not impacted by dry well contamination. Subsequent to this discovery, the system operation was shifted to that portion of the treatment plot containing subsurface contamination. The fact that a major portion of the system was installed over an uncontaminated area did not affect overall system performance; however, it did have some impact on cost.

- The cost for a full-scale remediation of soils at the Electro-Voice site, assuming that the total volume of contaminated soil to be remediated is 21,300 yd^3, is $220,737 or $10.36/$yd^3$. The largest cost component of the technology appears to be site preparation (28%), followed by analytical services (27%) and residuals/waste shipping, handling and storage (13%).

The following sections of this report contain the detailed information which supports the items summarized in this Executive Summary.

SECTION 1

INTRODUCTION

This section provides background information about the Super-fund Innovative Technology Evaluation (SITE) Program, discusses the purpose of this Innovative Technology Evaluation Report (ITER), and describes the SVVS process, For additional information about the SITE Program, this technology, and the demonstration site, key contacts are listed at the end of this section.

1.1 Background

The Subsurface Volatilization Ventilation System (SVVS) was developed by Billings and Associates, Inc. (BAI) in response to the increasing demand for integrated remedial systems, that address all phases of contamination problem in a faster, more effective, and less costly way than conventional remedial approaches. The SVVS is of particular interest because it promotes the in-situ destruction of volatile organic compounds (VOCs) by biodegradation and vapor extraction, reducing all phases of subsurface VOC mass without producing toxic by-products. Air circulation provides indigenous soil microbes with the oxygen required to complete the biochemical reactions that break down organic contaminants to harmless by-products (typically carbon dioxide and water), in the liquid, aqueous, sorbed and vapor phases. In addition, the continuous circulation of clean air encourages the mass transfer of VOCs to the vapor phase, which is withdrawn from the subsurface by a network of vacuum extraction wells, and is then treated above ground and released to the atmosphere.

Environmental Improvement Technologies, Inc. (EIT) holds the patents for the SVVS. In 1993, EIT received two patents, and a continuation -in -part, for their technology, indicating that a third patent was in the pipeline. BAI and B&RE acquired the rights to market the technology under a licensing agreement with EIT. The SVVS has been implemented at 70 sites in New Mexico, North Carolina, South Carolina, Florida, Minnesota, West Virginia, Illinois, Michigan, Pennsylvania, Texas and England. In 1991, the technology was accepted into the Superfund Innovative Technology Evaluation Program (SITE) to undergo a performance evaluation at the Electra-Voice facility in Buchanan, Michigan.

The Electra-Voice, Inc. (EV) facility is an active business located at 600 Cecil Street in the City of Buchanan Berrien County, Michigan. EV manufactures audio equipment and has been in operation at its present location since 1946. In February 1983, the facility was placed on the Michigan Act 307 and the Federal National

Priority List as a result of detectable concentrations of cyanide, xylenes, and toluene found in on-site monitoring wells. The groundwater contamination was originally attributed to the facility's two former wastewater lagoons. The facility has recently been the focus of an extensive remedial investigation/feasibility study (RI/FS), initiated shortly after EV and the US. Environmental Protection Agency (EPA) entered into an Administrative Order of Consent (AO) on October 8, 1987 (effective October 15, 1987). Studies initiated under the RI revealed the presence of organic and inorganic contaminants in soil and groundwater associated with a former fuel tank area and the former dry well area. The soils of the dry well area have been identified as the principal source of groundwater contamination, both on- and off-site. As per the Record of Decision (ROD), the dry well area is included in the first operable unit remedial action for the EV site; the specified remedial action for the dry well area is SVE followed by excavation, solidification and landfarming of any residuals. The dry well area was also selected as the location for the USEPA SITE demonstration. The SVVS was implemented and operated at the dry well area for a period of one year to evaluate the effectiveness of the technology for remediating subsurface organic contamination, to provide justification for the execution of an Explanation of Significant Difference (ESD) to the ROD for Operable Unit Number One.

1.2 Brief Description of Program and Reports

The SITE program is a formal program established by EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) in response to the Superfund Amendments and Reauthorization Act of 1986 (SARA). The SITE program promotes the development, demonstration, and use of new or innovative technologies to clean up Superfund sites across the country.

The SITE program's primary purpose is to maximize the use of alternatives in cleaning hazardous waste sites by encouraging the development and demonstration of new, innovative treatment and monitoring technologies. It consists of four major elements discussed below:

* the Emerging Technology Program,
* the Demonstration Program,
* the Monitoring and Measuring Technologies Program, and
* the Technology Transfer Program.

The Emerging Technology Program focuses on conceptually proven bench-scale technologies that are in an early stage of development involving pilot or laboratory testing. Successful technologies are encouraged to advance to the Demonstration Program.

The Demonstration Program develops reliable performance and cost data on innovative technologies so that potential users may assess the technology's site-specific applicability. Technologies evaluated are either currently available or close to being available for remediation of Superfund sites. SITE demonstrations are conducted on hazardous waste sites under conditions that closely simulate full-scale remediation conditions, thus assuring the usefulness and reliability of information collected. Data collected are used to assess: (1) the performance of the technology, (2) the potential need for pre- and post-treatment processing of wastes, (3) potential operating problems, and (4) the approximate costs. The demonstrations also allow for evaluation of long-term risks and operating and maintenance costs.

Existing technologies that improve field monitoring and site characterizations are identified in the Monitoring and Measurement Technologies Program. New technologies that provide faster, more cost-effective contamination and site assessment data are supported by this program. The Monitoring and Measurement Technologies Program also formulates the protocols and standard operating procedures for demonstrating methods and equipment.

The Technology Transfer Program disseminates technical information on innovative technologies in the Emerging Technology Program, Demonstration Program, and Monitoring and Measurement Technologies Programs through various activities. These activities increase the awareness and promote the use of innovative technologies for assessment and remediation at Superfund sites. The goal of technology transfer activities is to develop interactive communication among individuals requiring up-to-date technical information.

1.3 The SITE Demonstration Program

Technologies are selected for the SITE Demonstration Program through annual requests for proposals. ORD staff review the proposals to determine which technologies show the most promise for use at Superfund sites. Technologies chosen must be at the pilot- or full-scale stage, must be innovative, and must have some advantage over existing technologies. Mobile and in-situ technologies are of particular interest.

Once EPA has accepted a proposal, cooperative agreements between EPA and the developer establish responsibilities for conducting the demonstrations and evaluating the technology. The developer is responsible for demonstrating the technology at the selected site and is expected to pay any costs for transport, operations, and removal of the equipment. EPA is responsible for project planning, sampling and analysis, quality assurance and quality control, preparing reports, disseminating information, and transporting and disposing of treated waste materials.

The results of this evaluation of the SVVS vapor extraction/air sparging and in-situ bioremediation technology are published in two basic documents: the SITE Technology Capsule and this Innovative Technology Evaluation Report. The SITE Technology Capsule provides relevant information on the technology, emphasizing key features of the results of the SITE field demonstration. A Technology Evaluation Report (TER) is available as a supporting document to the ITER. Both the SITE technology capsule and the ITER are intended for use by remedial managers making a detailed evaluation of the technology for a specific site and waste.

1.4 Purpose of the Innovative Technology Evaluation Report (ITER)

This ITER provides information on the SVVS vapor extraction/in-situ bioremediation technology and includes a comprehensive description of the demonstration and its results. The ITER is intended for use by EPA remedial project managers, EPA on-scene coordinators, contractors, and other decision makers in implementing specific remedial actions. The ITER is designed to aid decision makers in further evaluating specific technologies for consideration as applicable options in a particular cleanup operation. This report represents a critical step in the development and commercialization of a treatment technology.

To encourage the general use of demonstrated technologies, EPA provides information regarding the applicability of each technology to specific sites and wastes. The ITER includes information on cost and performance, particularly as evaluated during the demonstration, It also discusses advantages, disadvantages, and limitations of the technology.

Each SITE demonstration evaluates the performance of a technology in treating a specific waste. The waste characteristics of other sites may differ from the characteristics of the treated waste. Therefore, a successful field demonstration of a technology at one site does not necessarily ensure that it will be applicable at other sites. Data from the field demonstration may require extrapolation for estimating the operating ranges in which the technology will perform satisfactorily. Only limited conclusions can be drawn from a single field demonstration,

1.5 Technology Description

The SVVS is an in-situ vacuum extraction/air sparging and bioremediation process designed to treat all phases of organic contamination in soil and groundwater. The technology promotes in-situ remediation through the injection of clean air into the saturated zone and the extraction of vapor phase contaminants in the vadose zone. This induced circulation of air in the subsurface encourages the mass transfer of VOC contaminants present as bulk liquid, dissolved and sorbed forms to a gas phase which is then extracted from the ground. The subsurface air circulation effectively oxygenates vadose zone soils, thereby stimulating aerobic microbiological processes which degrade organic contaminants. Vapor extraction removes the easily-strippable volatile components from the soil and/or groundwater and tends to be the dominant mechanism during the early phases of system operation. Bioremediation processes dominate the later phases of the application. Using the combination of vapor extraction and biostimulation is faster than the use of biostimulation alone, and reduces the amounts of volatile organics in the exhaust gasses than vapor extraction alone. Although the developer claims that more volatiles are mobilized because of vertically flowing air that strips more than just vadose zone soils, much of the mobilized mass is converted to biologically produced carbon dioxide.

The SVVS process consists of a network of injection and vacuum extraction wells plumbed to one or more compressors and vacuum pumps, respectively. The vacuum pumps create the negative pressure necessary to extract contaminant vapors. The air compressors simultaneously create positive pressures across the treatment area to deliver the oxygen needed to enhance aerobic biodegradation. The system is maintained at a vapor control unit (VCU) that houses the pumps, compressors, control valves, gauges and other process control hardware. Each SVVS process is custom-designed to meet specific site conditions. The number and spacing of the wells depends upon the physical, chemical and biological characteristics of the site, as well the results of a matrix-model. Depending on site conditions, subsurface vaporization can be enhanced via the injection of heated air. In addition, separate valves may be installed at the manifold of individual reactor lines, or on individual well points, for better control of air flow and pressures in the treatment area. Depending on groundwater depths and fluctuations, horizontal vacuum screens, “stubbed” screens, or multiple-depth completions can be applied. The system designed for each site is dynamic, allowing positive and negative air flow to be shifted to different locations in the subsurface to focus and concentrate remedial stresses on specific areas. Negative pressure is maintained at a suitable level to prevent the escape of vapors from the treatment area. If air quality permits require emission control, the developer claims that the system's vacuum extraction exhaust vapors can be treated by the BECs using the site's indigenous microbes.

1.6 **Key** Contacts

Additional information on the SVVS soil remediation technology and the SITE program Can be obtained from the following sources:

The SVVS Vapor Extraction/Air Sparging and In-Situ Bioremediation Technology

Steve Thompson
Project Manager
Brown & Root Environmental
464 1 Willoughby Road
Holt, Michigan 48842
517-694-6200

Mr. Jeff Billings
President
Environmental Improvement Technologies, Inc.
Billings and Associates, Inc.
3816 Academy Parkway, N-NE
Albuquerque, New Mexico 87109
505-345-l116

The SITE Program

Mr. Robert A. Olexsey, Director
Superfund Technology Demonstration Division
U.S. Environmental Protection Agenc
26 West Martin Luther King Drive

Cincinnati, Ohio **45268**
Phone: 513/569-7328
Fax: 513/569-7620

Mr. John Martin
EPA SITE Technical Project Manager
U.S. Environmental Protection Agency
26 West Martin Luther King Drive

Cincinnati, Ohio 45268
Phone: 5 13/569-7758
Fax: 5 13/569-7620

Information on the SITE **program** is available through the following on-line information clearinghouses

- The Alternative Treatment Technology Information Center (ATTIC) *System* (operator: 703-908-2137; access: 703-908-2138) is a comprehensive, automated information retrieval system that integrates data on hazardous waste treatment technologies into a centralized, searchable source. This data base provides summarized information on innovative treatment technologies.

- The Vendor Information System for Innovative Treatment Technologies (VISITT) (Hotline: 800-245-4505; Fax: 513-891-6685) database contains information on 231 technologies offered by 141 developers.

- The OSWER CLU-In electronic bulletin board *contains* information on the status of SITE technology demonstrations (Operator: 301-589-8368; Access: 301-589-8366).

Technical reports may be obtained by contacting the Center for Environmental Research Information (CERI), 26 Martin Luther King Drive in Cincinnati, OH 45268 at 513/569-7562.

SECTION 2
TECHNOLOGY APPLICATIONS ANALYSIS

This section of the report addresses the general applicability of the SVVS vapor extraction /air sparging and in-situ bioremediation technology to contaminated waste sites. The analysis is based on the SITE demonstration results, and conclusions are based exclusively on these data since only limited information is available on other applications of the technology. The SITE Demonstration was conducted on approximately 2,300 cubic yards of soil, of which an estimated 800 cubic yards were contaminated with varying levels of benzene, ethylbenzene, toluene, xylenes, trichloroethene, tetrachloroethene and 1,l -dichloroethene.

2.1 Key Features

The unique feature of the SVVS process is the integration and optimization of vapor extraction/air sparging and biostimulation principles for the in-situ treatment of subsurface organic contamination. The vapor extraction component destroys the easily-strippable VOC contaminants while the bioremediation component attacks the less volatile, more recalcitrant organics. The SVVS process can be used to remediate all phases (liquid, dissolved, sorbed, and vapor phases) of VOC contamination in soils and groundwater. As a result, the integrated SVVS process can treat contaminants that would normally not be remediated by vapor extraction alone (such as chemicals with lower volatility and/or chemicals that are tightly sorbed). Using the combination of vapor extraction and biostimulation is faster than the use of biostimulation alone, and reduces the amounts of volatile organics in the exhaust gasses that would be produced if vapor extraction was used alone. Unlike vapor extraction/air stripping technologies that often require off-gas treatment to ensure that emissions meet air quality standards, the SVVS limits the need for costly and space-consuming above-ground treatment (i.e., activated carbon or catalytic oxidation) of the extracted air stream. According to the developer, extracted vapors may need to be treated during the early stages of SVVS implementation, when the overall rate of mass transfer of contamination to the vapor phase exceeds the biodegradation rate. Eventually, as biodegradation rates surpass the net rate of contaminant transfer to the vapor phase, above-ground treatment of the extracted air stream is no longer needed. At this point vapor extraction off-gas will consist predominantly of carbon dioxide, a by-product of aerobic biodegradation. This reduced need for extracted air stream treatment during site remediation is reflected in decreased capital and operating costs. The SVVS also employs the use of BAI's biofiltration system (BECs) for the treatment of extracted vapors that further reduces the space requirements and costs associated with conventional vapor treatment technologies.

2.2 Operability of the Technology

The SVVS uses a network of injection and extraction wells designed to circulate air below the ground to facilitate the volatilization and removal of VOCs from the soil and groundwater, as well as to provide the oxygen necessary to enhance the rate of aerobic biodegradation of organics by indigenous soil microbes. Air injection wells are installed below the groundwater table and vacuum extraction wells are installed above the water table. The exact depth and screened intervals of these wells are site specific design considerations. A typical SVVS consists of alternating air injection and vacuum extraction wells aligned in rows referred to as "reactor lines". The reactor lines are linked together and plumbed to one or more compressors or vacuum pumps. The vacuum pumps create the negative pressure to extract contaminant vapors, while the air compressors simultaneously create positive pressures across the treatment area, to deliver oxygen for enhanced aerobic biodegradation, The system is maintained at a Vapor Control Unit (VCU) that houses pumps, control valves, gauges and other process control hardware. Each SVVS is custom-designed to meet specific site conditions. The number and spacing of the wells depends upon the modeling results of applying a design parameter matrix, as well as the physical, chemical and biological characteristics of the site. The SVVS design allows for flexibility in terms of system expansion and operation. Because of the simplicity of system construction, and the reserve capacity of air injection and vapor extraction built into a typical design, the cost of expansion (e.g., additional wells and reactor lines) would normally be no greater than 10% to 20% of the total project budget.. Details concerning the design of the SVVS evaluated under the SITE Demonstration Program are presented in Section 4.2.

The SVVS is a relatively simple system. Once installed, the technology requires only occasional maintenance and operator attention. Actual system operation requires extensive training and experience. If needed, the SVVS can incorporate its exclusive biofilters, known as Biological Emission Control (BEC) devices, to reduce the levels of VOCs in the extracted air stream in order to meet air quality standards. These devices are often taken off-line once the rate of biodegradation exceeds the net rate of transfer of contaminant mass into the circulating air. The BEC units were used at the beginning of the SITE Demonstration, but were taken out of service once the vacuum extraction exhaust gas met the discharge criteria that had been established with the state for discharge to the atmosphere.

Air flow management is the most important of the operating parameters that influence the performance of the SVVS remediation technology. Air flow adjustments are made to enhance subsurface conditions that stimulate the activity of the microbial populations responsible for the biodegradation of organic contaminants.

Air flow management is achieved at the Vapor Control Unit, or in some cases at each well head, through adjustment of control valves. This configuration allows optimal control of air input and vacuum rates, such that positive and negative air flow can be shifted to different locations of the treatment plot to concentrate remedial stress on the areas requiring it most. If a portion of the site is responding slowly, more remedial stress is applied through a series of valve adjustments. Conversely, less stress may be directed to portions of the site that are responding more rapidly, or have already been cleaned up to regulatory standards. Negative pressure is maintained at a suitable level to prevent escape of vapors.

The presence of indigenous microbes that utilize the organic contaminants as a food source is another potential operating parameter. Although not often necessary, periodic assessments of microbial activity and biotransformation capacities might be conducted. These assessments are determined through microbial assays, estimations of nutrient requirements, shut down testing and system-specific CO_2 data as follows:

- Microbial Populations: Depth-specific soil samples are collected over the course of the remediation to profile changes in the microbial populations resulting from system operation. Standard plate count methodologies are employed in the enumerations. Samples should be collected from areas containing significant contamination since it is in these areas that the presence of microbes is most important. According to the developer, these measures are no longer considered necessary when dealing with fuel related contamination because microbes have been found on all fuel sites, under many soil conditions.

- Nutrient Requirements: A baseline evaluation of the nutrient requirements necessary to sustain bacterial viability and growth might also be performed. The total mass of contamination within the area being treated is estimated, as well as that portion which is considered biodegradable. Based upon these mass estimates, the amounts of nitrogen and phosphorus needed by indigenous soil microbes to synthesize enough cell material to completely metabolize the total mass of contamination is calculated. These requirements are then compared to actual mass of nutrients available in the matrix. If insufficient nutrients are available, nutrient addition might be necessary to optimize the viability and activity of the soil microbes. According to the developer, these nutrient additions are seldom required.

- Bioremediation Rate: In-situ respiration or "shutdown" testing might be performed periodically to assess the progress of subsurface microbial activity. The magnitude of microbial activity is directly proportional to the rate of oxygen depletion. Ideally, the rate of oxygen depletion should be greatest where increased concentrations of degradable organic compounds are present.

- CO_2 Production: CO_2 measured at the vacuum extraction well heads as well as at the combined vapor extraction line, can provide information on microbial activity over the course of remediation, although it tends to be a less reliable indicator than O_2. An increase in CO_2 at these locations can be correlated to an increase in the biodegradation rates.

The types and phases of contaminants present also affect the performance of the SVVS Contaminants that are highly volatile are more amenable to vapor extraction, while less volatile contaminants respond best to biodegradation. Halogenated aliphatic compounds containing more than two halogens in their molecular structure are not particularly susceptible to biodegradation, but might be broken down into harmless end products in the presence of the less volatile degradable compounds via cometabolism. On the other hand, more tightly sorbed and less soluble compounds result in slower mass transfer and bioremediation rates.

Temperature also plays a key role in system performance. The rate of in-situ biodegradation and mass transfer of contaminants to the vapor phase is controlled in large part by temperature. The literature shows that metabolic reactions tend to occur rapidly under warmer conditions and considerably more slowly under cooler conditions. Contaminant vapor concentrations are dependent on temperature; therefore, removal rates are strongly influenced by subsurface temperatures. Most in-situ temperatures are warm enough to provide adequate rates of hydrocarbon biodegradation. Due to the relatively high thermal mass of soils and soil moisture and the low thermal mass of injection air, a great deal of operational time is required to cause a significant temperature change. During the winter months in northern climates, it is not uncommon for the SVVS to inject heated air to prevent a decrease in groundwater temperatures. Solar panels may be used for this purpose, or the pumps can be located within a heated building and the relatively warm air from the building can be injected into the ground. The VCU is also heated to increase longevity of the pumps, decrease condensate freezing problems, and maintain a hospitable environment for the microbes in the BEC units.

Soil pH can affect biodegradation. Ideally the pH should be within the range of 5.5 to 8.5 S.U. which is within the acceptable biological treatment range. Soils with higher and lower pHs might require adjustment prior to the implementation of the technology. This can be problematic with alkaline soils which are known for their large buffering capacity. Fortunately, pH adjustment is rarely necessary, since the indigenous microbes are typically adapted to the natural values found in the soil.

Soil permeability and stratification at a site influence the operational performance of the system by controlling air flow pathways. At a highly stratitied site, characterized by multiple geological horizons each with its own unique soil permeability, injected air will generally follow the course of least resistance and tend to travel laterally in coarser strata, potentially bypassing the target contaminations area. This lateral migration could also result in the spread of subsurface contamination as contaminant stripped from the groundwater and lower vadose zone travels laterally along the soil/water interface. If a site is highly stratified, sand chimneys are typically installed to enhance vertical air circulation. Sand chimneys are sand-packed borings which provide passive airflow between the subsurface layers, increasing both soil vapor extraction and biodegradation rates.

Local air quality standards might alter the operation and configuration of the SVVS. During the early stages of SVVS implementation the overall rate of mass transfer of contamination to the vapor phase, may exceed biodegradation rates. During this time, extracted vapors might require treatment before being released to the atmosphere. Off-gas extracted from the vacuum extraction wells can be routed through a configuration of Biological Emission Control (BEC) units, which according to the developer, can achieve up to 80% reductions in VOC stack emissions, at approximately 20% of the traditional emission costs. The exhaust from the BEC units may also be polished by vapor phase activated carbon, or catalytic oxidation to achieve near 100% VOC removal, if required. Vacuum extraction emissions can also be controlled within regulatory limits by adjusting the air injection and vacuum extraction rates.

2.3 Applicable Wastes

The SVVS process is suitable for the in-situ treatment of soil, sludges and groundwater contaminated with gasoline, diesel fuels, and other hydrocarbons, including halogenated compounds. The medium to be treated must not possess levels of toxic metals or any other compound that may be detrimental to the indigenous soil microbes. Although high levels of organic contamination, or disproportionately higher levels of halogenated VOCs over non-halogenated VOCs, may inhibit the performance of the microorganisms, the vapor extraction component of the SVVS process will eventually reduce the levels of these compounds to concentrations more suitable for biodegradation. Halogenated aliphatic compounds containing more than two halogens can be transformed to harmless end-products during or following the metabolism of natural substrates. The developer claims that the SVVS works effectively on benzene, toluene, ethylbenzene, and xylene (BTEX) contamination. The technology should be effective in treating soils and groundwater contaminated with virtually any material that exhibits volatility or is biodegradable. By changing the injected gases, anaerobic eonditions can be developed and a microbial population can be used to remove nitrate from groundwater. The aerobic SVVS can also be used to treat heavy metals in groundwater by raising the redox potential of the groundwater and precipitating the heavy metals.

In order for the bioremediation component of the system to be effective, prolific indigenous microbial populations must be present in the contaminated matrix. In rare situations where the microbial population is less prolific than is needed for the job, the indigenous communities can be augmented through the BioTrans™

technique. The process involves the isolation of dominant indigenous strains of hydrocarbon-degrading microbes obtained from soils or groundwater samples collected from biologically-active parts of the site. These strains are then cultivated until sufficient populations are produced, and the less biologically active portions of the site are then inoculated with the cultivated microbes. This technique was not used in the Demonstration, because suitable populations of indigenous microbes were already present.

2.4 Availability and Transportability of the Equipment

The SVVS is an in-situ remediation technology that is installed in-place and custom-designed to meet specific site conditions. For the most part, the technology is not considered mobile or transportable, although the developer has used a trailer mounted VCU for small sites and emergency response situations. Most of the hardware components used to construct and operate the system are common and readily available. Many of the components can be obtained at a hardware or plumbing supply store, and can be transported to the site by car or pickup truck.

System installation can take anywhere from a week to a month. The time it takes to install an SVVS largely depends on the number and depth of the injection and vacuum extraction wells. Installation requires a drill rig and a trained drill crew. Hollow-stem augering techniques are typically employed. A trenching device is also required for the horizontal installations of vacuum extraction and injection lines.

System demobilization activities consist of disconnecting utilities, and disassembling equipment housed in the VCU and transporting it off-site. Vacuum extraction and injection wells are either left in place as part of a facility's environmental monitoring program or are abandoned in accordance with state and local standards. Well abandonment will extend the length of time needed to demobilize a site.

2.5 Materials Handling Requirements

The materials handling requirements for the SVVS process are quite limited since the process is carried out "in-situ". For the most part, materials handling is only an issue during system installation. During installation, contaminated soil cuttings may be generated as a consequence of drilling and trenching activities. These cuttings typically require staging or storage in containers, such as 55-gallon steel drums or roll-off boxes, until arrangements can be made to dispose of them according to regulatory criteria. Materials handling during system installation can involve drill rigs, front-end loaders, backhoes and trenching equipment. The remediation area should be well graded and accessible to heavy equipment.

Sampling of soil before, during and after treatment may also require the use of materials handling equipment. Soil samples will be required to document that the regulatory cleanup criteria have been met, as well as to monitor microbial activity and biotransformation capacities. Soil sampling will likely require the use of a drill rig, a shovel or another device depending on the characteristics of the soil and the depths to be sampled.

Full-scale remediation of a site using SVVS generally includes an appropriately-sized configuration of BEC units to remove vapor phase contaminants from the vacuum extraction off-gas before release to the atmosphere. According to the developer, the BECs can also be used to treat condensate, well drilling wash water, cuttings and the ditching material to at least reduce the volume and off-site costs. Since the BEC units were used only briefly during the Demonstration, however, no conclusions could be drawn about their effectiveness. Vacuum extraction emissions may also be controlled within regulatory limits by adjusting the air injection and vacuum extraction rates. Special handling requirements might be required if activated carbon is needed for additional polishing of the off-gas. Appropriate arrangements will need to be made to store, regenerate and dispose of this material.

2.6 Site Support Requirements

Technology support requirements include utilities, support facilities, and support equipment. These requirements are discussed below.

The major utility required to operate the SVVS is electricity. 110 and 220 volt electrical hookups are required in the Vapor Control Unit (VCU). The 220 volt line is needed to power the injection air heater. The 110 volt line is needed to power the air compressors and vacuum pumps. These electrical services are commonly available, but might require a power drop to bring the electricity to the VCU. If power is unavailable and a connection to the power grid is considered unfeasible, diesel generators could be used.

Minor utility needs include a potable water supply, telephone and sewer service. Potable water is necessary for equipment decontamination and personnel needs. If potable water is unavailable, it can be trucked in. Phone service to the site is useful for general communication and for summoning emergency assistance. If a sewer hook up is not available, portable toilets can be used for sanitary purposes.

Support facilities required by the SVVS process include an enclosed heated area for housing pumps, control valves, gauges, emission control equipment, and other process hardware. This enclosed area is the system's Vapor Control Unit (VCU) where operational control of the SVVS is maintained. If a facility lacks the capacity to house these items, a temporary structure of sufficient size must be constructed to serve this purpose. The VCU must be heated to minimize climate-related problems with the equipment. Auxiliary buildings might be needed for storage of supplies and tools. A roll-off or drum staging area will be required for the temporary storage of drill cuttings generated during system installation.

Access to the site must be provided over roads suitable for travel by heavy equipment. Personnel must also be able to reach the site without difficulty. Depending on site location, security measures might be necessary to protect the public from accidental exposures and to prevent accidental and intentional damage to the equipment. A chain-link fence with a locking gate large enough to allow trucks to enter and leave should provide adequate security.

Support equipment needed during system installation and demobilization will likely include drill rigs and trenchers, and may involve earth moving equipment, forklifts, containers for storing drill cuttings and containers for waste water. Earth moving equipment, including backhoes and/or front-end loaders, will be needed for trenching and transferring drill cuttings to a roll-off or to drums, and, if necessary, regrading the site. A forklift or handtruck might be necessary for moving drums and supplies around the site. Support equipment needed during system operation should consist only of emission control devices. A configuration of BEC units (possibly coupled with vapor phase activated carbon or catalytic oxidation systems) might be required during the early phases of SVVS operation.

2.7 Ranges of Suitable Site Characteristics

Generally, SVVS is applicable and effective over a wide range of site characteristics. The site characteristics described in this section provide additional information about items which require consideration before applying the technology.

A candidate site must be well graded and accessible to drill rigs and other heavy equipment such as front-end loaders, backhoes, fork lifts, and trenching equipment. The subsurface should be free of utility lines or other underground facilities (i.e., fuel tanks). The subsurface should be free of large debris, such as might be found in a landfill. The contaminant plume should be accessible to allow the installation of an SVVS that provides adequate coverage of the plume.

The size and shape of the SVVS treatment plot should be in accordance with the dimensions and pattern of subsurface contamination as adjusted for permeability distribution, surface structures and contaminant phase. Typically, the network of vacuum extraction and injection wells are positioned directly over contaminated areas, therefore, these areas need to be accessible. Some of these problems can be overcome by using directional and horizontal drilling techniques for well emplacement. The site should provide additional space for the VCU structure and the drum staging or roll-off storage area. The VCU requires about 150 square feet. If a roll-off is utilized, sufficient area will be required to maneuver the roll-off in and out of the site. There should also be room for a waste water storage tank and a tank truck if potable water needs to be trucked in. A 20-square-foot decontamination area will need to be positioned so as to facilitate the decontamination of equipment and personnel during system installation and demobilization.

Soil characteristics at a particular site are instrumental in determining the site's suitability for the SVVS Relatively homogeneous fairly coarse soils are generally conducive to uniform as well as rapid contaminant reductions. Vertical variations in permeability, as is the case with highly stratified soils, may have a tendency to induce air to flow along horizontal pathways increasing the risk for contamination to spread laterally. Horizontal air flow can be controlled by a number of strategically placed sand chimneys. Sand chimneys, which are essentially sand/gravel filled boreholes, provide a vertical conduit for air flow and enhance air flow communication between all layers. Low soil permeabilities limit subsurface airflow rates and can reduce overall process efficiency. According to the developer, SVVS systems have been operated with success down to injection zone permeabilities of 10^{-6} cm/sec. Low permeability settings require special design considerations and operational methods, but do not necessarily negate SVVS success. Unlike some bioventing technologies, SVVS does not seem to be affected by low soil moisture since the air moving vertically from below the water table has a high humidity value.

Ideally, water tables should be more than several feet from the land surface, so as not to limit the effectiveness of vapor extraction and bioremediation as a result of reduced air flow. Some designs have been effective on sites with extremely shallow water tables by placing the vacuum lines above ground and covering them. The pavement or concrete used to cover the site would increase installation costs.

Soils with a high humic content could interfere with the application of SVVS by slowing down the cleanup due to increased organic adsorption and oxygen demand. Soils possessing a high iron content could produce deleterious geochemical reactions. (Induced precipitation caused by a change in the redox potential could cause clogging of the aquifer.) The problem would manifest itself by causing a major decrease in flow rate of injection and a synchronous increase in backpressure on the pumps. This problem would likely be limited only to those sites with very high dissolved iron concentrations and adequate groundwater flow to supply the iron at a rapid rate. The developer has yet to encounter such conditions, after applying the technology to over 70 site.

Since bioremediation is a major component of the SVVS technology, a site's soils should not contain appreciable amounts of toxic metals or any other compound that may be detrimental to the indigenous soil microbes. This has not been a problem to date with most fuel spill sites, but some of the larger hazardous waste sites might pose some problems.

The technology can be operated in nearly every climate. Since soil is a good insulating material, most in-situ temperatures are warm enough to provide adequate rates of hydrocarbon biodegradation even under colder surface conditions. Equipment can be climatized to prevent damage due to hot or cold conditions.

The SVVS process can be used in fairly close proximity to inhabited areas, as long as appropriate measures are taken to prevent off-site emissions, odors and noise. The SVVS produces little noise while operating, and emissions are controlled by the BEC units. Equipment must be transported to the site during installation; however, once the SVVS is operational, there is little additional traffic generated by the site.

2.8 Limitations of the Technology

In the application of any in-situ air sparging technology, it is imperative that the overall site remediation plan include a properly engineered soil vapor extraction (SVE) system to capture the contaminated vapors emanating from the saturated zone. Since the potential exists for enhanced migration of contaminant vapors off-site, the application of this technology is generally limited to sites where SVE is feasible. One possible exception to the requirement of an accompanying SVE system is a situation where the overall remediation system design relies on in-situ biodegradation to destroy the contaminant vapors in the vadose zone and vapor migration is not a concern.

The SVVS is generally not considered a mobile technology, although the developer occasionally employs a trailer mounted VCU for small sites and emergency response situations. The technology has to be installed and configured to address specific site problems. The installation is therefore intrusive and usually involves considerable digging, trenching and drilling. The installation phase can take up to a month to install and although the system components are simple, installation can be disruptive and noisy. During installation, workers might be exposed to chemical hazards from coming in contact with contaminated material. Workers must be advised of the chemical and physical hazards at the site and wear appropriate protective gear.

The effectiveness of SVVS is sensitive to soil air flow permeability, As discussed in the previous section, relatively homogeneous fairly coarse soils are generally conducive to uniform as well as rapid contaminant reductions. In highly stratified soils, air may travel far from the injection well along coarser strata and never reach shallower portions of the vadose zone. Horizontal air flow and the potential lateral spread of vapor phase contamination is typically stemmed by a number of strategically placed sand chimneys, also discussed in the previous section.

In situations in which dense non-aqueous phase liquids (DNAPLs) are present, it is possible to spread the immiscible phase and increase the size and concentrations of the VOC plume. This may actually be used to advantage in a site remediation to mobilize residuals and, in conjunction with groundwater control, realize a more efficient mass removal process.

SVVS may not be an economically beneficial alternative for remediation of materials of a very low permeability, although the developer claims that the technology has been operated with success down to an injection zone permeability of 10^{-6} cm/sec. In rare situations, potential geochemical changes may be induced through the application of the technology causing clogging of the aquifer. The potential for fouling may be evaluated using available geochemical models, or avoided by using a more appropriate gaseous medium.

2.9 ARARS for the SVVS Technology

This subsection discusses specific federal environmental regulations pertinent to the operation of the SVVS Vapor Extraction/In-Situ Bioremediation Technology including the transport, treatment, storage, and disposal of wastes and treatment residuals. Federal and state applicable or relevant and appropriate requirements (ARARs) are presented in Table 2-1. **These** regulations are reviewed with respect to the demonstration results. State and local regulatory requirements, which may be more stringent, must also be addressed by remedial managers. ARARs include the following: (1) the Comprehensive Environmental Response, Compensation, and Liability Act; (2) the Resource Conservation and Recovery Act; (3) the Clean Air Act; (4) the Safe Drinking Water Act; (5) the Toxic Substances Control Act; and (6) the Occupational Safety and Health Administration regulations. These six general ARARs are discussed below.

Table 2-l. Federal and State Applicable and Relevant and Appropriate Requirements (ARARs) for the SVVS Technology

PROCESS ACTIVITY	ARAR	DESCRIPTION OF REGULATION	GENERAL APPLICABILITY	SPECIFIC APPLICABILITY TO SVVS[a]
Waste characterization of untreated wastes	RCRA: **40 CFR** Part 261 (or state equivalent)	Standards that apply to identification and characterization of wastes	Chemical and physical analyses must be performed to determine if waste is a hazardous waste.	Chemical and physical properties of waste determine its suitability for treatment by SVVS
Soil excavation	CAA: 40 CFR Part 50 (or state equivalent)	Regulations governs toxic pollutants, visible emissions and . . particulates	If excavation is performed, emission of volatile compounds or dusts may occur.	Applies to construction activities (i.e., drilling and trenching) during system installation.
Waste processing	RCRA: **40 CFR Part 264 (or state** equivalent)	Standards that apply to treatment of wastes in a treatment facility	When hazardous wastes are treated, there are requirements for operations, recordkeeping, and contingency planning.	Applicable or appropriate for SVVS operations.
	CAA: 40 CFR Part **50 (or state equivalent)**	Regulation govern toxic pollutants, visible emissions and particulates	Stack gases may contain volatile organic compounds or other regulated gases.	During SVVS operations, stack gases must not exceed limits set for the air district of operation. Standards for monitoring and recordkeeping apply.

Table 2- 1. (Continued)

PROCESS ACTIVITY	ARAR	DESCRIPTION OF REGULATION	GENERAL APPLICABILITY	SPECIFIC APPLICABILITY TO SVVS®
Storage of auxiliary wastes	RCRA: **40 CFR** Part **264** Subpart J (or state equivalent)	Regulation governs standards for tanks at treatment facilities	If storing non-RCRA wastes, RCRA requirements may still be relevant and appropriate	Storage tanks for liquid wastes (e.g., decontamination waters and condensate) must be placarded appropriately, have secondary containment and be inspected daily.
	RCRA: **40 CFR** Part **264** Subpart I (or state equivalent)	Regulation cover storage of waste materials generated	Applicable for RCRA wastes; relevant and appropriate for non-RCRA wastes	Roll-offs or drums containing drill cuttings need to be labeled as hazardous waste. The storage area needs to be in good condition, weekly inspections are required, and storage should not exceed 90 days unless a storage permit is obtained.
Determination of cleanup standards	SARA: Section 121(d)(2)(ii); SDWA: 40 CFR Part 141	Standards that apply to surface and groundwater sources that may be used as drinking water	Remedial actions of surface and groundwater are required to meet MCLGs (or MCLs) established under SDWA	Applicable and appropriate for SVVS for projects that require groundwater to be treated.

Table 2- 1. (Continued)

PROCESS ACTIVITY	ARAR	DESCRIPTION OF REGULATION	GENERAL APPLICABILITY	SPECIFIC APPLICABILITY TO SVVS[a]
Waste disposal	RCRA: 40 CFR Part 262	Standards that pertain to generators of hazardous waste	Generators must dispose of wastes at facilities that are permitted to handle the waste. Generators must obtain an EPA ID number prior to waste disposal.	Waste generated by the the SVVS is limited to contaminated drill cuttings. Spent activated carbon could be another waste if carbon is used in the treatment of system off gases.
	CWA: 40 CFR Parts 403 and/or 122 and 125	Standards for discharge of wastewater to a POTW or to a navicable waterway	Discharge of wastewaters to a POTW must meet pre-treatment standards; discharges to a navigable waterway must be permitted under NPDES.	Applicable and appropriate for decontamination wastewaters and condensate.
	RCRA: 40 CFR Part 268	Standards regarding land disposal of hazardous wastes	Hazardous wastes must meet specific treatment standards prior to land disposal, or must be treated using specific technologies.	Applicable for off-site disposal of auxiliary waste (e.g., drill cuttings and other waste soils).

2.9.1 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

The CERCLA of 1980 as amended by the Super-fund Amendments and Reauthorization Act (SARA) of 1986 provides for federal funding to respond to releases or potential releases of any hazardous substance into the environment, as well as to releases of pollutants or contaminants that may present an imminent or significant danger to public health and welfare or to the environment.

As part of the requirements of CERCLA, the EPA has prepared the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) for hazardous substance response. The NCP is codified in Title 40 Code of Federal Regulations (CFR) Part 300, and delineates the methods and criteria used to determine the appropriate extent of removal and cleanup for hazardous waste contamination.

SARA states a strong statutory preference for remedies that are highly reliable and provide long-term protection and directs EPA to do the following:

- use remedial alternatives that permanently and significantly reduce the volume, toxicity, or mobility of hazardous substances, pollutants, or contaminants;
- select remedial actions that protect human health and the environment, are cost-effective, and involve permanent solutions and alternative treatment or resource recovery technologies to the maximum extent possible; and
- avoid off-site transport and disposal of untreated hazardous substances or contaminated materials when practicable treatment technologies exist [Section 121 (b)].

The SVVS process meets each of these requirements. Volume, toxicity and mobility of contaminants in the waste matrix are all reduced as a result of treatment. Organic compounds are either stripped from contaminated matrices to be biodegraded ex-situ in a configuration of biofilters or biodegraded in-situ by indigenous soil microbes. In both cases, contaminants are subject to biochemical reactions that convert them to cell material and energy for metabolic processes. The by-products of these reactions are innocuous and normally consist of carbon dioxide and water. The need for off-site transportation and disposal of solid waste is eliminated by in-situ treatment. Vacuum extraction off-gas may require treatment prior to release to the atmosphere.

In general, two types of responses are possible under CERCLA: removal and remedial action. Super-fund removal actions are conducted in response to an immediate threat caused by a release of hazardous substances. Removal action decisions are documented in an action memorandum. Many removals involve small quantities of waste or immediate threats requiring quick action to alleviate the hazard. Remedial actions are governed by the SARA amendments to CERCLA. As stated above, these amendments promote remedies that permanently reduce the volume, toxicity, and mobility of hazardous substances, pollutants, or contaminants. The SVVS process is likely to be part of a CERCLA remedial action.

On-site remedial actions must comply with federal and more stringent state ARARs. ARARs are determined on a site-by-site basis and may be waived under six conditions: (1) the action is an interim measure, and the ARAR will be met at completion; (2) compliance with the ARAR would pose a greater risk to health and the environment than noncompliance; (3) it is technically impracticable to meet the ARAR; (4) the standard of performance of an ARAR can be met by an equivalent method; (5) a state ARAR has not been consistently applied elsewhere; and (6) ARAR compliance would not provide a balance between the protection achieved at a particular site and demands on the Super-fund for other sites. These waiver options apply only to Super-fund actions taken on-site, and justification for the waiver must be clearly demonstrated.

2.9.2 Resource Conservation and Recovery Act (RCRA)

RCRA, an amendment to the Solid Waste Disposal Act (SWDA), is the primary federal legislation governing hazardous waste activities and was passed in 1976 to address the problem of how to safely dispose of municipal and industrial solid waste. Subtitle C of RCRA contains requirements for generation, transport, treatment, storage, and disposal of hazardous waste, most of which are also applicable to CERCLA activities. The Hazardous and Solid Waste Amendments (HSWA) of 1984 greatly expanded the scope and requirements of RCRA.

RCRA regulations define hazardous wastes and regulate their transport, treatment, storage, and disposal. If soils are determined to be hazardous according to RCRA (either because of a characteristic or a listing carried by the waste), all RCRA requirements regarding the management and disposal of hazardous waste must be addressed by the remedial managers. Criteria for identifying characteristic hazardous wastes are included in 40 CFR Part 261 Subpart C. Listed wastes from specific and nonspecific industrial sources, off-specification products, spill cleanups, and other industrial sources are itemized in 40 CFR Part 261 Subpart D. For the

Demonstration Test, the technology was subject to RCRA regulations because the Electra-Voice site is a Superfund site contaminated with RCRA-listed wastes including benzene, ethylbenzene, toluene, xylenes, trichloroethene, 1,l-dichloroethene, and tetrachloroethene. RCRA regulations do not apply to sites where RCRA-defined hazardous wastes are not present.

Unless they are specifically delisted through delisting procedures, hazardous wastes listed in 40 CFR Part 261 Subpart D remain listed wastes regardless of the treatment they may undergo and regardless of the final contamination level in the streams and residues. This implies that even after remediation, “clean” wastes are still classified as hazardous because the pre-treatment material was a listed waste.

For generation of any hazardous waste, the site responsible party must obtain an EPA identification number. Other applicable RCRA requirements may include a Uniform Hazardous Waste Manifest (if the waste is transported), restrictions on placing the waste in land disposal units, time limits on accumulating waste, and permits for storing the waste.

Requirements for corrective action at RCRA-regulated facilities are provided in 40 CFR Part 264, Subpart F (promulgated) and Subpart S (Partially promulgated). These subparts also generally apply to remediation at Superfund sites. Subparts F and S include requirements for initiating and conducting RCRA corrective action, remediating groundwater, and ensuring that corrective actions comply with other environmental regulations. Subpart S also details conditions under which particular RCRA requirements may be waived for temporary treatment units operating, at corrective action sites and provides information regarding requirements for modifying permits to adequately describe the subject treatment unit.

2.9.3 Clean Air Act (CAA)

The CAA establishes national primary and secondary ambient air quality standards for sulfur oxides, particulate matter, carbon monoxide, ozone, nitrogen dioxide, and lead. It also limits the emission of 189 listed hazardous pollutants such as vinyl chloride, arsenic, asbestos and benzene. States are responsible for enforcing the CAA. To assist in this, Air Quality Control Regions (AQCR) were established. Allowable emission limits are determined by the AQCR, or its sub-unit, the Air Quality Management District (AQMD). These emission limits are determined based on whether or not the region is currently within attainment for National Ambient Air Quality Standards (NAAQS).

The CAA requires that treatment, storage, and disposal facilities comply with primary and secondary ambient air quality standards, Fugitive emissions from the SVVS technology may come from (1) excavation and drilling activities related to system installation (volatile organic compounds or dust), (2) periodic sampling efforts, (3) the staging and storing of contaminated drill cutting and (4) treated exhaust gas during system operation. Soil moisture should be managed during system installation to prevent or minimize the impact from fugitive emissions. State air quality standards may require additional measures to prevent fugitive emissions. The off-gas treatment system must be adequately designed and air injection and vacuum extraction rates controlled to meet current air quality standards. State air quality standards may require additional measures to prevent emissions.

2.9.4 Clean Water Act (CWA)

The objective of the CWA is to restore and maintain the chemical, physical, and biological integrity of the nation's waters. To achieve this objective, effluent limitations of toxic pollutant from point sources were established. Publicly-owned treatments works (POTWs) can accept wastewaters with toxic pollutants; however the facility discharging the waste water must meet pre-treatment standards and my need a discharge permit. A facility desiring to discharge water to a navigablewaterway must apply for a permit under the National Pollutant Discharge Elimination System (NPDES). When an NPDES permit is issued, it includes waste discharge requirements for volumes and contaminant concentration.

The only waste water produced by the SVVS process that might need to be managed is waste water generated during equipment decontamination and condensate that accumulates in the air lines. Decontamination water could amount to several thousand gallons depending on the level of effort involved to install a SVVS Condensate should only be a fraction of this volume. Some of this water may be used as makeup water for the BECs during startup and system operation. Additional water that is generated and not utilized in the BECs will require analysis for the organic contaminants found in the site matrices that are targeted for treatment. Depending on the levels of contaminants and the volume of this waste water, pretreatment might be required prior to discharge to a POTW.

2.9.5 Safe Drinking Water Act (SDWA)

The SDWA of 1974, as most recently amended by the Safe Drinking Water Amendments of 1986, requires the EPA to establish regulations to protect human health from contaminants in drinking water. The legislation authorized national drinking water standards and a joint federal-state system for ensuring compliance with these standards.

The National Primary Drinking Water Standards are found in 40 CFR Parts 141 through 149. These drinking water standards are expressed as maximum contaminant levels (MCLs) for some constituents, and maximum contaminant level goals (MCLGs) for others. Under CERCLA (Section 12 1(d)(2)(A)(ii)), remedial actions are required to meet the standards of the MCLGs when relevant. For the SVVS demonstration, treatment of groundwater was a secondary objective but this may not hold true at other sites or during different applications of the process.

2.9.6 Toxic Substances Control Act (TSCA)

The TSCA of 1976 grants the EPA authority to prohibit or control the manufacturing, importing, processing, use, and disposal of any chemical substance that presents an unreasonable risk of injury to human health or the environment. These regulations may be found in 40 CFR Part 76 1; Section 6(e) deals specifically with PCBs. Materials with less than 50 ppm PCB are classified as non-PCB; those containing between 50 and 500 ppm are classified as PCB-contaminated; and those with 500 ppm PCB or greater are classified as PCB. PCB-contaminated materials may be disposed of in TSCA-permitted landfills or destroyed by incineration at a TSCA-approved incinerator; PCBs must be incinerated. Sites where spills of PCB-contaminated material or PCBs have occurred after May 4, 1987 must be addressed under the PCB Spill Cleanup Policy in 40 CFR Part 761, Subpart G. The policy establishes cleanup protocols for addressing such releases based upon the volume and concentration of the spilled material. It has not been documented that the SVVS process is useful for PCB-contaminated wastes to date.

2.9.7 Occupational Safety and Health Administration (OSHA) Requirements

CERCLA remedial actions and RCRA corrective actions must be performed in accordance with the OSHA requirements detailed in 20 CFR Parts 1900 through 1926, especially § 1910.120 which provides for the health and safety of workers at hazardous waste sites, On-site construction activities at Super-fund or RCRA corrective action sites must be performed in accordance with Part 1926 of OSHA, which describes safety and health regulations for construction sites. State OSHA requirements, which may be significantly stricter than federal standards, must also be met.

All technicians and subcontractors involved with the installation and operation of the SVVS Vapor Extraction/In-Situ Bioremediation system are required to have completed an OSHA training course and must be familiar with all OSHA requirements relevant to hazardous waste sites. Workers on hazardous waste sites must also be enrolled in a medical monitoring program. The elements of any acceptable program must include: (1) a health history, (2) an initial exam before hazardous waste work starts to establish fitness for duty and a medical baseline, (3) periodic examinations (usually annual) to determine whether changes due to exposure may have occurred and to ensure continued fitness for the job, (4) appropriate medical examinations after a suspected or known overexposure, and (5) an examination at termination.

For most sites, minimum PPE for workers will include gloves, hard hats, safety glasses, steel-toe boots, and Tyvek. Depending on contaminant types and concentrations, additional PPE may be required, including the use of air purifying respirators or supplied air. Noise levels during the operation of the SVVS are not expected to be high, except during the construction, which will involve the operation of heavy equipment. During these activities, noise levels should be monitored to ensure that workers are not exposed to noise levels above a time-weighted average of 85 decibels over an eight-hour day. If noise levels increase above this limit, workers will be required to wear ear protection. The levels of noise anticipated are not expected to adversely affect the community, depending on its proximity to the treatment site.

The SVVS VCU could be considered a confined space. Special consideration should be made during the construction of the VCU to provide adequate ventilation. Otherwise workers will be required to comply with the recently promulgated OSHA requirements for confined spaces (29 CFR § 1910.146), including requirements for stand-by personnel, monitoring, placarding, and protective equipment. Since the installation of the SVVS will require some excavation, trenches could be considered additional confined spaces (based on type and depth) and the same requirements would have to be met. Other construction- or plant-related OSHA standards may also apply while installing and operating a SVVS, including shoring of trenches, and lock-out/tag out procedures on powered equipment.

2.9.8 State Requirements

In many cases, state requirements supersede the corresponding Federal program, such as OSHA or RCRA, when the state program is Federally approved and the requirements are more strict. The state of Michigan had other regulatory requirements which are not covered under the major Federal Programs including special requirements for operating on a floodplain.

SECTION 3
ECONOMIC ANALYSIS

3.1 Introduction

This economic analysis is based on assumptions and costs provided by B&RE and on results and experiences from the SITE demonstration operated over a l-year period at the Electra-Voice site, located in Buchanan MI. The costs associated with treatment by the SVVS process, as presented in this economic analysis, are defined by 12 cost categories that reflect typical cleanup activities performed at Super-fund sites. Each of these cleanup activities is defined and discussed; they form the basis for an estimated cost analysis of a full-scale remediation at the same site.

The SVVS is applicable to sites contaminated with gasoline, diesel fuels, and other hydrocarbons, including halogenated compounds. The technology can be applied to contaminated soils, sludges, free-phase hydrocarbon product, and groundwater. The EV site included all of these. A number of factors could affect the estimated cost of treatment. Among them, were: the type and concentration of contaminants, the extent of contamination, groundwater depth, soil moisture, air permeability of the soil, site geology, geographic site location, physical site conditions, site accessibility, required support facilities and availability of utilities, and treatment goals. It is important to thoroughly and properly characterize the site before implementing this technology, to insure that treatment is focused on contaminated areas. This cost may be substantial, but is not included here. Even if the treated area is offset from the contaminated area, as was the case in the SITE demonstration, the process is still effective in removing the contamination, showing that there is some flexibility in applying this technology. However, there will probably be an associated increase in costs in terms of the length of treatment required to achieve a certain cleanup level. Another key factor that may not be accurately predictable without a pilot test is the radius of influence and, consequently, the number of wells needed to remediate a particular site. The cost of conducting such a pilot study is also not included here.

The economic analysis for a full-scale remediation at this site was done as a base case, assuming that the performance was similar to that demonstrated under the SITE program. Cost figures provided here are “order-of-magnitude” estimates, and are generally +500%/-30%.

3.2 Conclusions

* **The cost to** remediate **2 1,300 yd^3** of vadose zone soils during a full-scale cleanup over a 3-year period at the Electra-Voice Superfund site in Buchanan, MI was estimated to be $220,737 or **$10/yd^3**, not including effluent treatment and disposal. The majority of this was incurred in the first year, primarily due to site preparation.

* The largest cost component was Site Preparation (28%), followed by Analytical Services (27%), and Residuals & Waste Shipping, Handling, and Storage (13%). These four categories accounted for 68% of total costs. The next largest component was Labor (9%), indicating that this technology is not labor-intensive, although travel, per diem, and rental car expenses were not considered. Capital Equipment, and Utilities each accounted for 6% of costs, with the remainder of the categories each accounting for 5% *or* less.

* If Effluent Treatment and Disposal costs had been included, this would have added $164,500 to the first year of remediation and brought the total cleanup figure to $385,237 **($18.09/yd^3)**. This would have accounted for over 43% of the total cleanup cost.

3.3 Issues and Assumptions

This section summarizes the major issues and assumptions used to evaluate the cost of a full-scale SVVS remediation of the Electra-Voice Superfund site in Buchanan, MI. In general, assumptions are based on information provided by B&RE and observations made during the demonstration project.

3.3.1 <u>Waste Volumes and Site Size</u>

This economic analysis assumes that the site and wastes have already been thoroughly and properly characterized and that these results were used to design the SVVS process; i.e. number, placement, and depth of wells; amount of air injection and extraction; size of blower and vacuum pump; size of piping; valving arrangements; etc. Therefore, it does not include the costs for treatability studies, waste characterization tests, pilot studies or system design and layout. All of these activities would add to the costs and time required for remediation.

For a full-scale cleanup, the treatment area was still assumed to be the vadose zone (depth = 46 ft), but enlarged to an area of 100 ft x 125 ft, for a total volume of 575,000 **ft^3** (21,300 **yd^3**). This is about ten times the volume of soil that was treated under the SITE project.

It is reasonable to assume that if the source of groundwater contamination lies within the vadose zone, then any reduction in vadose zone contamination will translate to a reduction of groundwater contamination. This was not evident from the SITE demonstration results, because significant concentrations of contamination were not present in the groundwater beneath the treatment plot.

3.3.2 System Design and Performance Factors

The system design proposed by BAI to remediate contaminated soils associated within the dry well area included 10 air injection wells, 15 vacuum extraction wells, and 10 sand chimneys. The number of wells and sand chimneys proposed for the full-scale design is only slightly greater than that used for the SITE demonstration. This means that the amount of overlap in the radius of influence between wells would be less. This would translate into a level of removal less than what was achieved in the demonstration for a one year time frame. However, if it is assumed that the full-scale system would give the same level of removal as that demonstrated under the SITE project, then the cleanup would likely take longer. B&RE has suggested 3 years instead of 1 year. The tacit assumption is that this level of removal is sufficient to meet regulatory standards.

It should be mentioned that sand chimneys have been incorporated into the design because of the highly stratified nature of the soils at this site. For a site where the soils are more homogeneous, sand chimneys would not normally be necessary. Their costs are minimal and have not been included here.

The Biological Emission Control (BEC) units, which were designed to biologically degrade extracted VOCs from the off-gas stream, were taken off-line a few months into the Demonstration when the exhaust off-gasses met the site specific emission criteria. The off-gas was discharged without further treatment throughout the remainder of the Demonstration. The same scenario was assumed for the full-scale remediation, i.e., no effluent treatment of off-gasses. However, because this may not be the case at other sites, the cost of adding carbon adsorption onto the back end of the system is discussed under "Effluent Treatment and Disposal Costs".

3.3.3 Svstem Operating Requirements

The SITE project demonstrated that the equipment was quite reliable and required minimal operator oversight . Therefore, the system used for economic analysis was assumed to be operated 24 hours a day, 7 days a week for 3 years continuously. Any maintenance, modifications or adjustments to the system were assumed to be done during one of the 12 sampling events scheduled to take place every year.

3.3.4 Financial Assumptions

For purposes of this analysis, capital equipment costs have been amortized over an assumed useful life span of 10 years with no salvage value. Interest rates, inflation, or the time value of money have not been accounted for. Insurance and taxes are assumed to be fixed costs listed under "Startup" and are calculated as 10% of annual capital equipment costs.

3.4 Basis for Economic Analysis

In order to compare the cost effectiveness of technologies in the SITE program, EPA breaks down costs into the twelve categories shown in Table 3-1 using the general assumptions already discussed. The assumptions used for each cost factor are discussed in more detail below.

3.4.1 Site Preparation

The amount of preliminary preparation would depend on the site, and was assumed to be performed by the responsible party (or site owner) in conjunction with the developer. Site preparation responsibilities include site design and layout, surveys and site logistics, legal searches, access rights and roads, and preparations for support facilities, decontamination facilities, utility connections, and auxiliary buildings. None of these costs have been included here.

The focus, instead, was on technology-specific site preparation costs. These are generally one-time charges and are necessarily site-specific. They include the drilling and preparation of wells, SVVS installation and construction oversight, utility connections, and a building enclosure to house the VCU and any associated effluent treatment system(s).

TABLE 3-1 ESTIMATED COST FOR TREATMENT USING THE SVVS® PROCESS OVER A THREE YEAR APPLICATION			
COST CATEGORY	**1st Year**	**2nd Year**	**3rd Year**
1. Site Preparation			
Well Drilling & Preparation	$32,500	------	-------
Building Enclosure (10'x15')	$10,000	....	-------
Utility Connections	$5,000	------	---------
System Installation	$15,000	------	-------
Total Costs	$62,500	-------	-------
2. **Permitting & Regulatory Requirements**	**$10,000**		
3. **Capital Equipment (amortized over 1Oyrs)**			
Vacuum Pump	$450	$450	$450
Blower	$450	$450	$450
Plumbing	$3,333	$3,333	$3,334
Building Heater	$333	$333	$334
Total Costs	$4,566	$4,566	$4,568
4. startup	$7,957	_______	-----
5. Consumables & Supplies			
Health & Safety Gear	**$1,000**	$1,000	**$1,000**
6. **Labor**	$6,300	$6,300	$6,300
7. **Utilities**			
Electricity(Blower & Pump)	$3,900	$3,900	$3,900
Electricity(Heater)	$660	$660	$660
Total Costs	$4,560	$4,560	$4,560
B. Effluent Treatment & Disposal Costs	**N/A**	**N/A**	**N/A**
9. **Residuals & Waste Shipping & Handling**			
Contaminated Drill Cuttings	$12,500	------	$6,000
Contaminated PPE	$6,000	$1,000	$3,000
Total Costs	$18,500	$1,000	$9,000
10. Analytical	$20,000	$20,000	$20,000
11. Maintenance & Modifications	**N/A**	**N/A**	**N/A**
12. Demobilization	---------	---------	$2,508
TOTAL ANNUAL COSTS	**$135,383**	**$37,426**	**$47,928**
TOTAL REMEDIATION COST	**$220,737**		

Drilling and preparation (purging, casing, caps, etc.) of injection/extraction wells were assumed to be performed by a subcontractor at an average cost of $1,300 per well. For a total of 25 wells -- 10 injection and 15 extraction, the total drilling cost is $32,500 ($1,3OO/well x 25 wells). B&RE has estimated that it would take about 4 weeks @ 50 man-hr/wk to completely install the SVVS and provide construction oversight services. Assuming a labor rate of $75/man-hr, the total cost of labor for system installation and construction oversight would be $15,000 (4 wk x 50 man-hr/wk x $75/man-hr). Based on SITE demonstration experience, it was estimated that utility connections would total about $5,000, and that a 10 ft x 15 ft building enclosure would cost about $10,000 to construct.

Hence the total site preparation cost is estimated to be $62,500 and has been assigned only to the first-year in Table 3-1.

3.4.2 Permitting and Regulatory Requirements

These costs may include actual permit costs, system health/safety monitoring, and analytical protocols. Permitting and regulatory costs can vary greatly because they are very site- and waste-specific. Based on their SITE demonstration experience, B&RE estimated permitting costs at about $10,000. Although some of these costs may be spread out over the course of the project, the majority of these expenses will be incurred in the first year.

3.4.3 Capital Equipment

Most of the capital equipment cost data were provided by B&RE. They include a 5 HP blower costing $4,500, a 5 HP vacuum pump costing $4,500, and a 2,550 watt heater for the building enclosure costing $1,000. This totalled $10,000, and the cost for plumbing (pipes, pipe fittings, valves, gauges, etc.) was assumed to cost an equal amount, i.e. $10,000.

The cost of the blower and vacuum pump can be amortized over a l0-year useful life span because these pieces of equipment can be removed at the end of the three year cleanup and used elsewhere. Hence, their combined annualized costs would be $900 as shown in Table 3-1. The plumbing and heater, on the other hand, would probably remain. Therefore, their combined costs ($11,000) will have to be amortized over 3 years, or $3,667 annually as shown in Table 3-1 for every year of remediation.

Since the BECs were not used for a substantial part of the Demonstration, they are not included here. However, the cost of including carbon adsorption to control emissions is discussed under "Effluent Treatment and Disposal Costs".

3.4.4 Startup

Transportation costs are variable and dependent on site location, and size/weight load limits, which vary from state to state. Transportation costs are only charged to the client for one direction of travel. Since they are not expected to be a major factor, they are not included here.

Based on their SITE demonstration experience, B&RE has estimated that startup and shakedown testing will require about 2 weeks @ 50 man-hr/wk. Assuming a labor rate of $75/man-hr, the total labor cost for startup and shakedown would be about $7,500 (2 wk x 50 man-hr/wk x $75/man-hr). Fixed costs, such as insurance and taxes, were included at a rate of 10% of the total annualized capital equipment costs, or $457 (0.1 x $4,566). The total startup costs are $7,957 and have been assigned to the first year of remediation only.

3.4.5 Consumables and Supplies

The SVVS, as applied to this site, did not employ any microbial inoculations or nutrient addition. Therefore there are no costs attributable to that aspect of the process. The costs for maintenance supplies (spare parts, oil, grease, lubricants, etc.) were considered negligible and so were not included either.

The only other item that may have to be included in this category is health and safety gear, and miscellaneous supplies. This was estimated to be about $1,000/yr and is included as a yearly line item in Table 3-1.

3.4.6 Labor

Hourly labor rates include base salary, benefits, overhead, and general and administrative (G&A) expenses. Travel, per diem, and rental car costs have not been included in these figures. If a site is located such that extensive travel will be required, that could have a major impact on labor costs.

Based on their experiences with the SITE demonstration, B&RE estimated that an average of 12 sampling events per year would be required to monitor and consequently modify and/or adjust the operation of their system. Periodic routine maintenance tasks could also be done during these sampling events. They estimated that each event would require 7 man-hr. Therefore, at $75/man-hr the total labor cost would be $6,300 (12 events/yr x 7 man-hr/event x $75/man-hr).

The labor associated with other tasks, such as site preparation, startup, and demobilization have been assigned to those categories. The demobilization hourly rate is slightly lower ($50/man-hr) because B&RE feels that less skilled labor would be required to accomplish this task.

Utilities

The major utility demand for this project was electricity, primarily to run the blower, vacuum pump, and heater. The blower and pump were both rated at 5 HP or 3.73 kW. Assuming electricity costs $0.06/kWh, the annual utility costs associated with these two pieces of equipment are $3,900 (2 x 3.73 kW x 24 hr/day x 365 day/hr x $0.06/kWh). The heater would presumably be used only during cold weather. If it is assumed that this would amount to no more than 180 days/yr, then the heater would cost $660/yr (2.55 kW x 24 hr/day x 180 day/yr x $0.06/kWh) to operate. The total of these would be $4,560 for each year of the cleanup.

Effluent Treatment and Disposal

Based on experience from this SITE demonstration, the off-gas was discharged without further treatment, based on air dispersion modeling. That was also assumed to be the case for the full-scale remediation. Therefore, no costs were assigned to effluent treatment and disposal. However, this may not be the case at other sites.

To get an idea as to how much impact this would have, a carbon adsorption unit was hypothetically assumed to be required at the back end of the SVVS. The carbon unit was sized based on the SITE demonstration result, that showed approximately 300 kg of VOCs were extracted over a one-year period. Since the full-scale remediation assumes treatment of ten times the amount of soil treated during the SITE demonstration, about 3,000 kg of VOCS were assumed to be extracted. If it is conservatively estimated that 10 kg of carbon are required for each kg of VOC extracted, then 30,000 kg of carbon would be necessary for treatment over 1 year. It was also assumed that VOC concentrations in the extracted off-gas would be low enough at the end of the first year that carbon adsorption would not be required for the remainder of the cleanup.

Rental of a stainless steel vessel with 820 kg of vapor phase reactivated carbon (the largest size currently available) would cost about $4,500/unit, including spent carbon handling and off-site reactivation. The unit would have to be replaced 36 times over the course of a year (30,000 kg ÷ 820 kg/unit). Additionally, there would be a one-time RCRA carbon acceptance fee of $2,500 to sample the spent carbon to ensure safe reactivation. Therefore, if treatment of the off-gas had been required, it would have cost an additional $164,500 ($4,500/unit x 36 units/yr + $2,500).

3.4.9 Residuals & Waste Shipping, Handling, and Storage

During the SITE demonstration, approximately 1 drum of well cuttings was produced for each well. For the full-scale remediation, this would translate to 25 drums of well cuttings. The cost to manifest, transport, handle, and dispose of these was estimated at $500/drum. The cost to dispose of these is then calculated to be $12,500 (25 drums x $500/drum). In the fmal year an additional 10 drums of well cuttings were assumed to be generated due to regulatory site closure requirements. The only other residual that would require disposal is personal protective equipment (PPE). It was assumed that 2 drums of PPE would be generated during the second year and slightly more in the last year of cleanup. The total cost for this category is then $28,500.

3.4.10 Analytical Services

Based on their experience with the SITE demonstration, B&RE estimated that they would need to have an average of 12 sampling events each year. The labor cost for this has been included under "Labor". However, an additional expense associated with laboratory analyses needs to be included. The developer will use this information to optimize the operation of his system by periodically adjusting or modifying its operation. This has been estimated at $20,000 per year but may be as low as $10,000 per year and is included in Table 3-1.

3.4.11 Facilitv Modification, Repair. and Replacement

Based on experience from the SITE demonstration, no further modification, repair, and/or replacement, other than routine system adjustment, was projected. As stated earlier, this is assumed to be done during the sampling events, site preparation, or startup. No additional costs for this have been included.

3.4.12 <u>Demobilization</u>

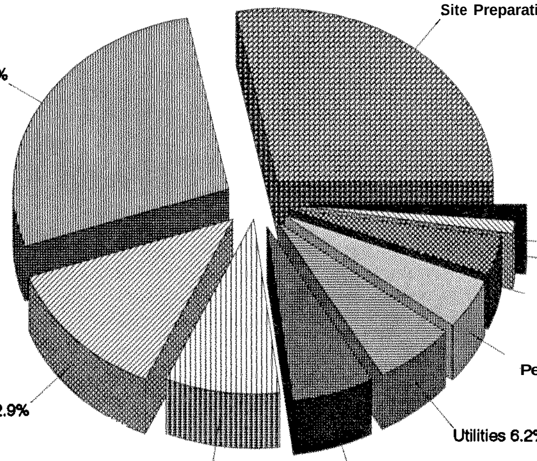
Based on their experience from the SITE demonstration, B&RE estimated that it would take 1 week @ 50 man-hr/wk to demobilize the site. A labor rate of $5O/man-hr was used because it was felt that a less skilled level of effort was required to demobilize. The total cost for demobilization is then $2,500 (1 wk x 50 man-hr/wk x $5O/man-hr), which would be incurred in the last year of remediation.

3.5 Results

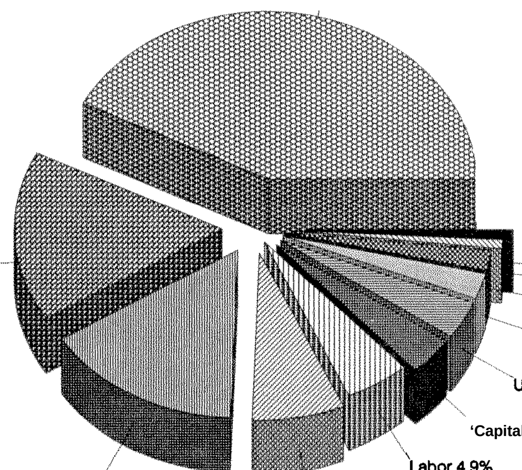
Table 3-1 shows the itemized costs for each of the 12 categories on a year-by-year basis for a hypothetical 3 year full-scale remediation of the Electra-Voice Superfund site located in Buchanan, MI. The total cost to remediate 21,300 yd^3 of soil was estimated to be $220,737 or $10.36/yd^3$. This figure does not include any treatment of the off-gases. If effluent treatment costs are included; it would increase costs to $385,237 or $18.09/yd^3$.

Figure 3-I shows the relative importance of each category on overall costs. It shows the largest cost component to be Site Preparation (28%), followed by Analytical Services (27%), and Residuals/Waste Shipping, Handling & Storage (13%). Labor accounted for a relatively small percentage (9%). This is indicative of the fact that the SVVS is a relatively reliable, non-labor intensive process. (However, travel, per diem, and car rental expenses were not included.) These four categories alone accounted for 68% of the costs. Utilities and Capital Equipment each accounted for about 6%, and the remaining categories each accounted for 5% or less. If effluent treatment costs had been included, it would have accounted for over 43% of the total cleanup cost.

FIGURE 3-I
Remediation Cost Breakdown (3 yrs.)
(Without Effluent Treatment)



(With Effluent Treatment)



SECTION 4
TREATMENT EFFECTIVENESS

This section presents the results of the SITE demonstration conducted at the Electro-Voice Facility located in Buchanan Michigan. The section discusses the effectiveness of the SVVS in remediating subsurface VOC contamination near the facility's former dry well.

4.1 Background

The SVVS SITE Demonstration was conducted at the Electra-Voice Facility in Buchanan, Michigan. Electra-Voice, Inc. contracted Brown & Root Environmental (formerly Halliburton NUS Environmental Corporation) to install and operate an SVVS over a one-year period. Baseline and system operations data were gathered to evaluate the effectiveness of the system for remediating volatile organic compound (VOC)-contaminated soils related to former paint waste disposal practices at the facility. The results would be used to provide a justification for the execution of an Explanation of Significant Difference (ESD) to the Record of Decision (ROD) for Operable Unit Number One.

Electra-Voice, Inc. is an active facility in the business of manufacturing audio equipment. The technology was installed and tested in an open field behind the facility where paint shop wastes had previously been discharged to the subsurface via a dry well. The dry well was installed in 1964 as part of the facility's automated painting system and was used to dispose of liquid waste via a gravity drain connected to a sink in the paint shop. Use of the dry well had been discontinued by 1973. Soil sampling conducted during a Remedial Investigation, and subsequently by the USEPA SITE Program, indicated that petroleum and chlorinated aliphatic hydrocarbons were detectable in soil samples throughout much of the vadose zone of the "dry well area". The magnitudes of these contaminants are most significant in soil samples acquired in the immediate vicinity of the former dry well. The greatest concentrations of VOCs were encountered in a subsurface horizon referred to as the "sludge-layer". This sludge layer, occurring 12 to 18 feet below the surface, is a discolored clay-rich horizon containing filtrate from wastes that have leached from the dry well.

A VOC analysis of the sludge layer from the SITE Demonstration Pretreatment Borehole SB- 16, drilled at the location of the former dry well, yielded toluene, ethylbenzene, and total xylenes at concentrations of 4,300 mg/kg 1,400 mg/kg and 6,600 mg/kg respectively. Tetrachloroethene, trichloroethene and 1,1,1-trichloroethane were also detected at 240 mg/kg, 23 mg/kg and 18 mg/kg respectively. The remedial investigation (RI) report for the Electra-Voice site states that the total mass of contamination associated with the dry well soils may be as much as 1,000 kg.

Under the SITE Program, the SVVS was evaluated for its ability to reduce volatile organic contaminants in the vadose zone soils of the "dry well" area. The critical objective of the demonstration was to evaluate the developer's claim of a 30% reduction in the sum of the concentrations of seven specific volatile organic compounds (i.e., benzene, toluene, ethylbenzene, xylenes, tetrachloroethene, trichloroethene and 1,1-dichloroethene) in vadose zone soils of the treatment plot over a 12 month period of operation. It is important to note that the one year time frame was chosen for testing purposes only, and the reduction claim does not reflect the limits of the technology. During an actual clean-up, the system may require longer time than was possible under the present study.

Secondary objectives for the Demonstration Test are as follows:

- Monitor the reduction of volatile organic compounds in the saturated soil and groundwater within the SVVS Treatment Plot.
- Monitor the impact of the technology on the groundwater outside the immediate treatment area.
- Qualitatively determine the magnitude of contaminant reduction due to vapor extraction versus in-situ biodegradation by performing a baseline soil gas test and three shut-down soil gas monitoring tests.
- Determine the magnitude of reduction of individual contaminants (benzene, toluene, ethylbenzene, xylenes, tetrachloroethene, trichloroethene and 1,1-dichloroethene) within vadose zone soils of the dry well area.
- Monitor general soil conditions (i.e., nutrients, toxics) that might inhibit or promote the system's effectiveness, such as: Total Carbon (TC), Total Inorganic Carbon (TIC), Nitrate, Phosphate, Ammonia, Total Kjeldahl Nitrogen, Sulfate, Alkalinity, Total Metals plus Mercury, Cyanide, pH, and Particle Size Distribution (PSD).
- Monitor the effectiveness of the biofilter in the reduction of VOC contamination in the extracted air stream.
- Monitor the extracted air stream to qualitatively assess biodegradation in the treatment plot over the course of the demonstration.
- Develop an estimation of operating costs for the SVVS technology in remediating VOC contamination.

4.2 Detailed Process Description

The SVVS, developed and designed by BAI, and operated by B&RE under a licensing agreement, integrates the benefits of both vapor extraction and bioremediation in the removal and destruction of all phases of organic contamination from the subsurface. Vapor extraction removes the easily-strippable volatile compounds from the soil and/or groundwater and appears to be the dominant mechanism during the early phases of remediation. Bioremediation, more specifically biostimulation, processes are more dominant in the later phases of a remediation and are used to accelerate the in-situ destruction of organic compounds in the soil and groundwater. The combined application of the technologies results in remediation that is more rapid than the use of biostimulation alone, while generating lower quantities of volatile organics than conventional vapor extraction technologies. An additional benefit is the remediation of contaminants that would not normally be remediated by vapor extraction alone (chemicals with lower volatilities and/or chemicals that are more tightly sorbed). The result is an integrated technology that translates into lower costs and faster remediations.

A typical SVVS is comprised of a network of air injection and vacuum extraction wells designed to circulate air below the ground to:

* Volatilize and remove volatile organic contaminants from the groundwater and soil
* Increase the flow of oxygen in the soil to enhance the rate of in-situ transformations and destruction of organic contaminants by indigenous soil microbes.

An SVVS is custom-tailored to address specific site conditions. A typical SVVS consists of alternating air injection and vacuum extraction wells aligned together in rows referred to as reactor lines. The number and spacing of the wells depends upon modeling results of applying a design parameter matrix, as well as the physical, chemical and biological characteristics of the site. The reactor lines are linked together and plumbed to a central vapor control unit (VCU) used to house air injection and vacuum pumps, gauges, control valves and other process control hardware. The VCU may also house an emission treatment system. One or more vacuum pumps are used to create negative pressure to extract contaminant vapors and control vapor migration, while an air compressor simultaneously creates positive pressure across the treatment area. Vacuum extraction wells are generally placed above the water table and are typically screened in the zone of maximum contamination to better focus remedial stresses. Air injection wells are screened below the groundwater table. The exact depth of the injection wells and screened intervals are site-specific design considerations. Depending on groundwater depths and fluctuation, horizontal vacuum screens, “stubbed” screens, or multiple-depth completions may be an option. Solar panels or passive heated air injection may also enhance subsurface volatilization, particularly in the winter months. Additional valves may be placed on individual reactor lines or on the individual wells for better control of air flow and pressure. The SVVS design allows positive and negative air flow to be shifted to different locations of the treatment plot so as to concentrate remedial stress on those areas requiring it.

The SVVS at the Electra-Voice site is comprised of three separately-valved reactor lines. Figure 4-1 presents a schematic diagram of the SVVS configuration at the Electro-Voice facility. The Electra-Voice design consists of 11 vacuum extraction wells and 9 air injection wells, each separately valved for optimum system flexibility and air flow control. The air injection wells are installed into the water table with a one foot screened interval positioned approximately 10 feet beneath the water table in the dry well area (water table in the dry well area is approximately 50 feet below grade). The vacuum extraction wells were installed such that a five-foot section of screen is set to intersect the “sludge layer”. The extraction wells were installed with a five-foot blank with a drain port attached to the bottom of the screen to control condensation. A number of sand chimneys were installed to better facilitate vertical air circulation throughout the plot. The injection and vacuum air supply lines of each reactor line are manifolded to a single injection and vacuum line inside the VCU Building. The pumps used during the SITE Demonstration are BAI V5, capable of 85 cubic feet per minute (cfm) reverse pressure air flow, and BAI A5, capable of delivering 120 cfm air flow. Typically, the positive (injection) pressure pump flow rate is maintained at approximately 80% of the vacuum pump flow rate. In addition to the various technology control systems, the VCU contained the Biological Emission Control (BEC) units to further reduce levels of VOC in the extracted air stream prior to release to the atmosphere.

The soil vapor extraction element of the process operates by pumping clean air into the injection wells to percolate upward through the saturated and unsaturated zone, making contact with volatile organic contaminants. The continuous circulation of clean air encourages the mass transfer of bulk liquid, dissolved and sorbed phase contamination to the vapor phase. Vacuum extraction wells installed in the vadose zone pull the percolated air through the soil under vacuum, further enhancing the mass transfer or stripping of contaminants and control the migration of contaminated vapors.

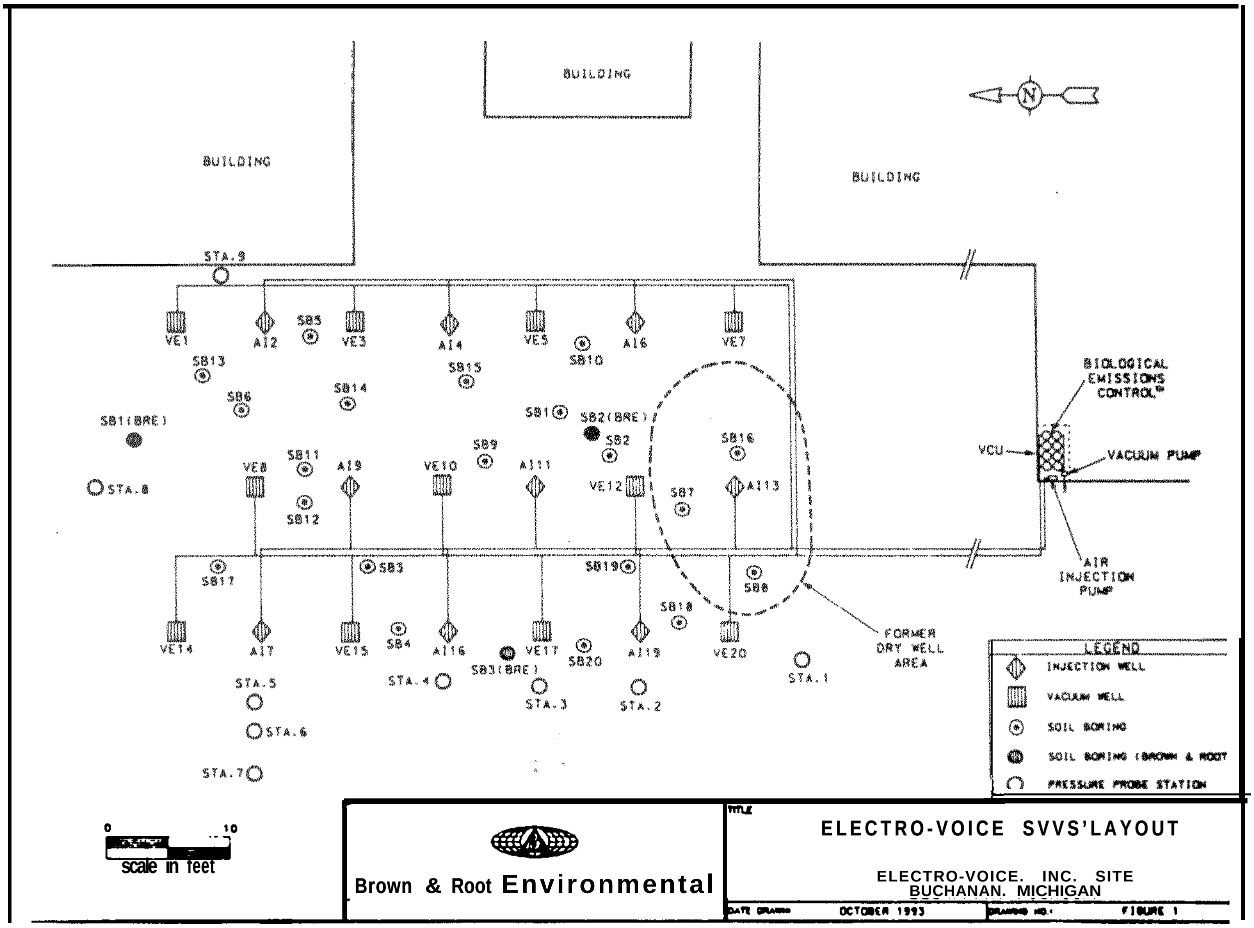


Figure 4-l

Configuration of the SVVS™ at the Electra-Voice Site

The increased circulation of air in the groundwater and soil, specifically oxygen, also stimulates and accelerates natural biodegradation. A steady supply of oxygen allows those microbes that respire aerobically to utilize the organic contaminants as a food source, thus converting these organic substrates to cell material and energy for metabolic processes. By-products of these metabolic reactions are carbon dioxide and water. As long as oxygen is supplied, and a food source remains, the microbial populations proliferate and biodegradation rates increase.

During the early stages of an SVVS operation, the overall rate of mass transfer of contaminants to the vapor phase may exceed the biodegradation rates. This phase, according to the developer, may last anywhere from two weeks to a few months. The extracted vapors may need to be treated above ground before release to the atmosphere. The amount of treatment will decrease steadily over this period until biodegradation rates surpass the net rate of transfer of contaminant mass into the circulating air. When this point is reached, the vapor extraction off-gas will consist predominantly of carbon dioxide and water, and treatment of the exhausted air stream should no longer be necessary.

4.3 Methodology

The primary goal of the project was to determine the effectiveness of the SVVS in reducing VOC contamination in the vadose zone. In order to determine the effectiveness of the technology, contaminant levels in the vadose zone prior to installation were compared to contaminant levels after one year of operation. Soil samples were collected from randomly-located borings within the physical boundaries of the S VVS system and composited in such a manner that the entire vertical section of the vadose zone was represented. Because the developer's claim was to reduce seven volatile organic contaminants by 30%, benzene, toluene, ethylbenzene, and xylenes (BTEX), as well as tetrachloroethene (PCE), trichloroethene (TCE), and 1, I-dichloroethene (1,l -DCE) were considered the critical parameters for this demonstration. Analyses were also performed on select samples for the following non-critical parameters: total carbon (TC), total inorganic carbon (TIC), nutrients (nitrate, phosphate), total metals plus mercury, cyanide, pH, and particle size distribution (PSD). An additional objective of this demonstration was to develop data on operating costs for the SVVS technology.

Pre-treatment sampling activities were conducted to establish a baseline. It was estimated that 77 samples were statistically required to evaluate the developer's claim of 30% reduction, based on subsurface contaminant variability, derived from the analysis of paired Predemonstration borehole characterizations. Soil samples were obtained from 20 boreholes randomly positioned within the treatment plot (Figure 4-2). Distinct sub-surface horizons were classified according to lithology and contaminant levels. The horizons were designated the Upper Horizon, Sludge Layer, Lower Horizon A1, Lower Horizon A2, Lower Horizon B, and the Saturated Zone. Samples were collected from each of these horizons. These borehole samples were extracted/composited into methanol in the field and shipped to the contract laboratory to be analyzed for VOCs to establish the initial vadose zone concentrations in the contaminated area within the treatment system. After sampling, all boreholes were backtilled with clean fill possessing textural properties similar to the soil removed from the borehole, so as not to influence the operation of the treatment technology.

Saturated zone samples were considered non-critical and were not part of the sample set for claim evaluation. The impact of the technology outside the immediate treatment area was inferred based upon subsurface pressures measured at pressure probe stations installed around the perimeter of the treatment plot.

Groundwater quality was monitored by collecting samples from existing groundwater monitoring wells MW-1, MW-2, MW-3, MW-4, and predemonstration well SAIC MW-1 at times 0,3,6,9 and 12 months. These samples were also analyzed for VOCs for determination of a secondary objective. The monitoring wells are located approximately 100 to 200 feet down and across gradient from the treatment plot.

The magnitude of contaminant reduction due to vapor extraction versus in-situ biodegradation was qualitatively determined by conducting system. "shut-down" tests and monitoring carbon dioxide (CO_2), oxygen (0_2) and total hydrocarbons (THC) in the gas. These tests occurred in the first month (to establish baseline conditions), at 6 months, and upon completion of the demonstration after 12 months.

Analyses on the extracted air stream were utilized to evaluate the soil vapor extraction (SVE) component of the technology. Air samples were periodically collected before and after the BEC devices, and were analyzed for critical volatile components. Volumetric flow rates were also measured to determine mass removal rates of extracted vapors.

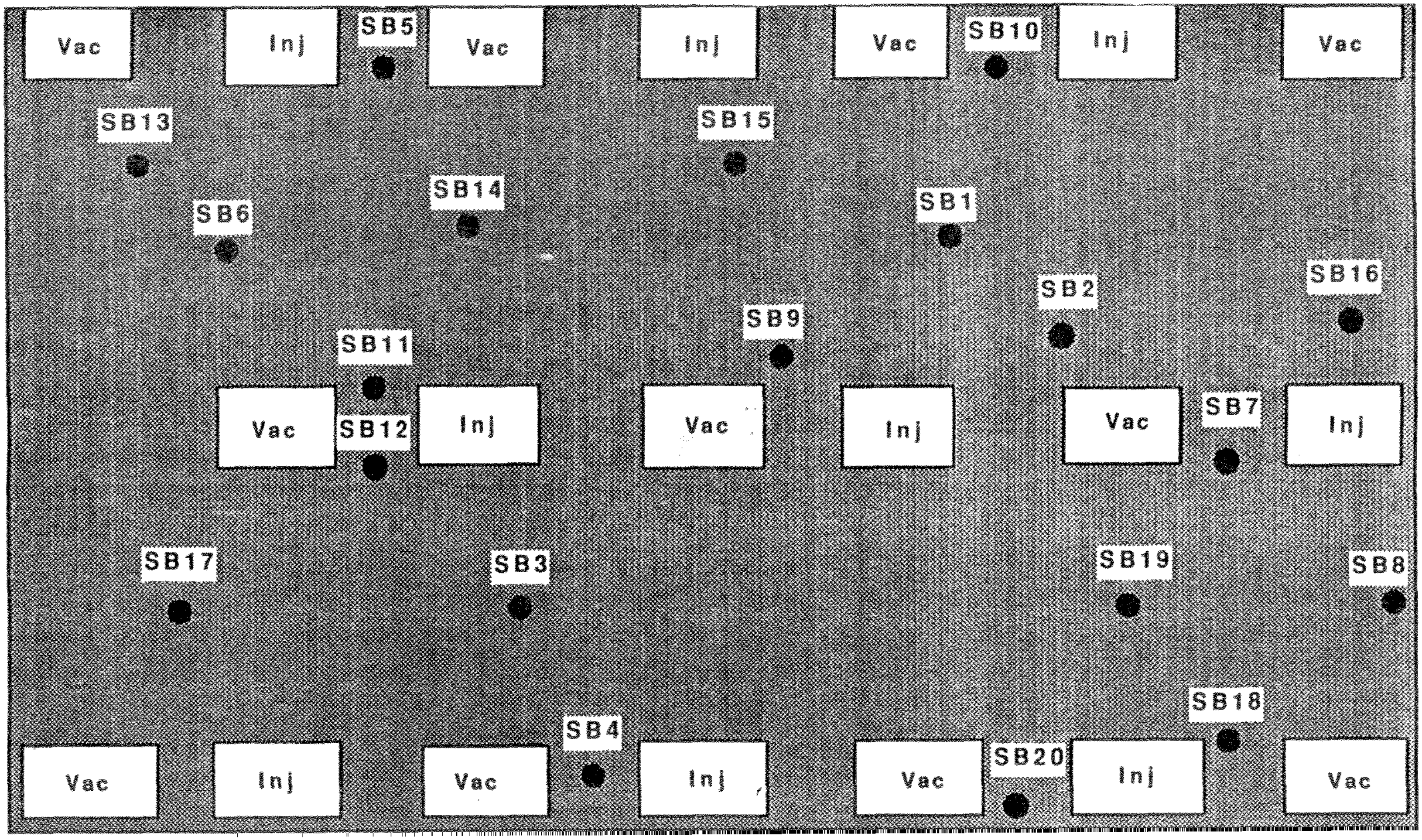


Figure 4-2

Pre-Treatment Sampling Locations at the Electra-Voice Site

Legend

Inj- Injection
Vac- Vacuum
- Study Area
- Soil Borings
NOT TO SCALE

4.4 Performance Data

This section presents the performance data gathered by the testing methodology described above. Results are presented and interpreted in the subsequent sections. Data is presented in tabular and/or graphic form.

4.4.1 Results from Pre-Treatment Study

A review and analysis of the pre-treatment VOC data from the 120 vadose zone samples indicate that a significant portion of the designated treatment area (thirteen boreholes; SB-1,3,4,5,6,9, 10, 11, 12, 13, 14, 15, and 17) had target VOC concentrations near or below their respective detection limits and thus did not serve as an appropriate test matrix to determine the capability and effectiveness of the SVVS treatment technology. The sparsely-contaminated portion of the treatment area containing these thirteen boreholes is designated Zone II and is shown in Figure 4-3. Data from the remaining seven boreholes (SB-2,7,8, 16,18,19, and 20) defines an appropriately contaminated area to evaluate the SVVS. This area is designated Zone I as depicted in Figure 4-3.

Post-treatment sampling utilized 14 boreholes drilled in the redefined hot-zone (Zone I) with paired boreholes at each of the seven pre-treatment boring locations. Paired boreholes were selected in order to reduce statistical variability. In addition to the fourteen boreholes in Zone I, post-treatment samples were recovered from Zone II boreholes SB-1,3,6,9, and 10. These were recovered to insure that contamination was not migrating to these portions of the site.

4.4.2 Summary of Results - Primary Objectives

The developer's claim for a 30% reduction in vadose zone contamination was greatly exceeded. The average reduction in the sum of the critical volatile components averaged 80.6% over a one year period. This value was calculated from the boreholes in the hot-zone (Zone I). The average concentration before implementation of the SVVS was 341.5 mg/kg; this average was reduced to 66.2 mg/kg after one year of operation. A t-test was performed on log normal transformed total VOC data to determine if the reductions observed were significant, The results of the t-test indicate that the reductions observed were significant with a 90% confidence level.

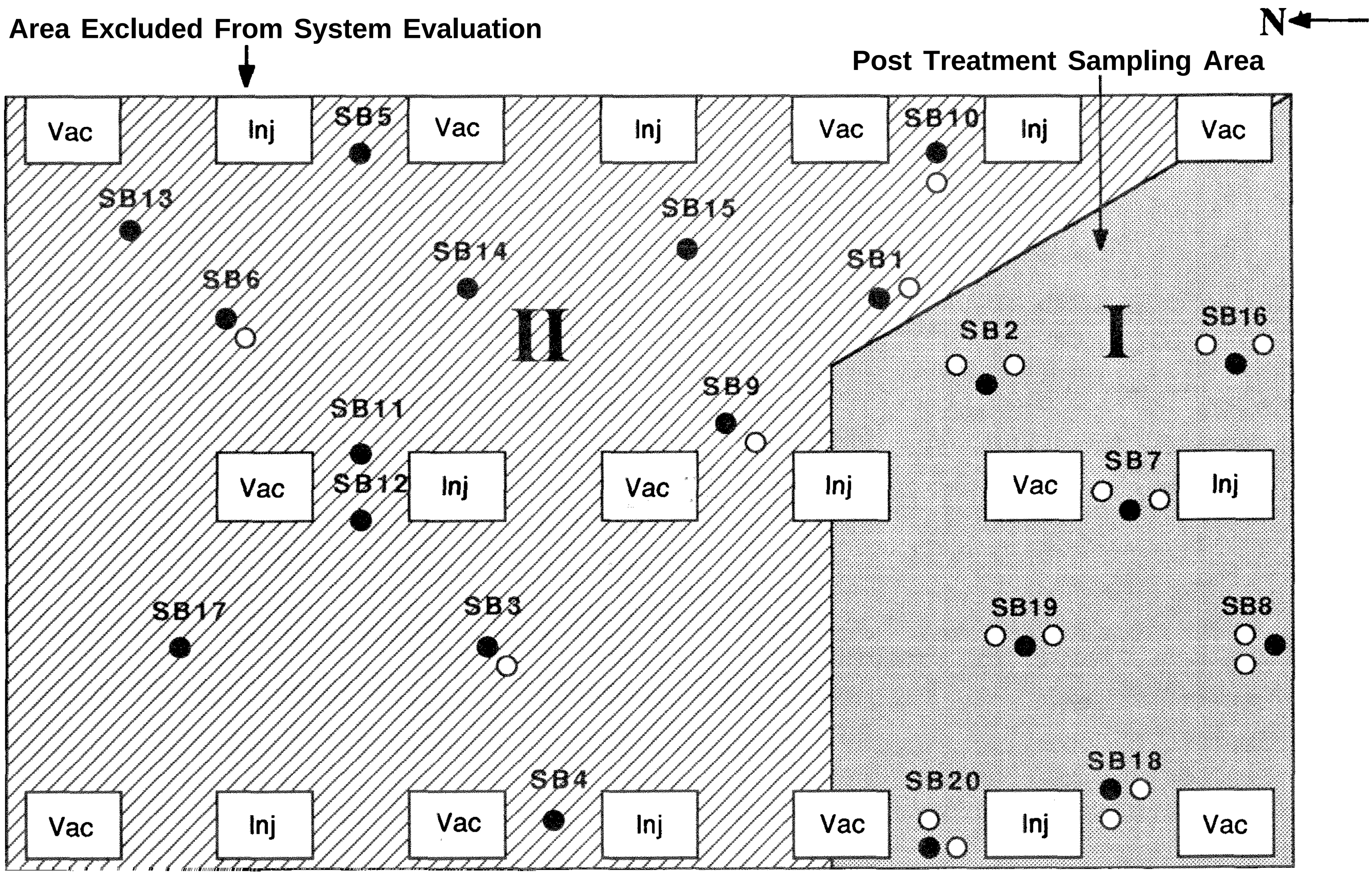


Figure 4-3

Revised Post-Treatment Sampling Locations at the Electro-Voice Site

LEGEND	
Inj	- SVVS Injection Well
Vac	- SVVS Vacuum Well
●	- Pre-Treatment Soil Borings
○	- Post-Treatment Soil Borings
	NOT TO SCALE

Table 4-1 summarizes the performance of the SVVS by sub-surface horizon, and Figure 4-4 graphically depicts the data. The highest concentration of the critical VOCs occurred in the sludge layer, which had an average concentration of 1,661 mg/kg before implementation of the system. After one year of operation, the concentration in the sludge layer was 308 mg/kg, an 81% reduction in contamination. Pre-treatment concentrations in the other zones ranged from 14 mg/kg to 322 mg/kg, with post-treatment concentrations averaging less than 1 mg/kg for all horizons (98 to >99% reductions). Figure 4-5 is a plot of the percent reduction versus initial concentration for all sub-surface horizons in each borehole. The plot shows no strong correlation between initial concentration and reduction effectiveness; therefore, the technology is not limited by concentration, and is operative over a wide contaminant concentration range.

Performance of the SVVS over the areal extent of the entire treatment plot (Zones I and II) is illustrated by comparing pre-treatment and post-treatment contaminant maps for the entire vadose zone (Figure 4-6), as well as for each sub-surface horizon (Figures 4-7 to 4-10). As previously discussed, a large portion of the treatment plot contained very low concentrations of contaminants as illustrated in Figure 4-6a. The installation and operation of the system in an uncontaminated portion of the site did not affect the performance of the system in the highly contaminated portion, as illustrated in the post-treatment contaminant map (Figure 4-6b) However, installation of the system in nonumtaminated sub-surface soils is an inefficient use of resources that may impact remedial cost. This situation emphasizes the need to accurately define the location and extent of sub-surface contamination prior to implementation. Cost-effective in-situ remediation technologies require a high level of site characterization to insure that the treatment agents are reaching the impacted media.

An analysis of the contaminant maps before and after treatment for individual layers (Figures 4-7 to 4-10) reveal that the. sludge layer is the only layer that did not undergo almost complete remediation. The sludge layer did exhibit significant reductions in contaminant concentration and areal extent as a result of the SVVS.

4.4.3 Changes in Individual Critical VOCs

The effectiveness of the SVVS treatment on individual critical VOCs is summarized in Table 4-2 and graphically depicted in Figures 4-11 and 4-12. Pre-treatment soil analyses indicate that the non-

TABLE 4-1
SVVS® PERFORMANCE SUMMARY
ZONE 1 VADOSE SOILS ("HOT ZONE")

TREATMENT PLOT HORIZONS	CRITICAL VOCs* CONCENTRATION (mg/kg)		% REDUCTION
	PRETREATMENT SAMPLING	POST-TREATMENT SAMPLING	
Upper Horizon	321.77	0.74	99.77%
Sludge Layer	1661.03	307.69	81.48%
Lower Horizon A1	96.42	0.98	98.99%
Lower Horizon A2	37.68	0.42	98.88%
Lower Horizon B	13.57	0.30	97.79%

* *Sum of Benzene, Toluene, Ethylbenzene, Xylene, 1,1-Dichloroethene, Trichloroethene and Tetrachloroethene*

Figure 4-4 SVVS Performance by Horizon

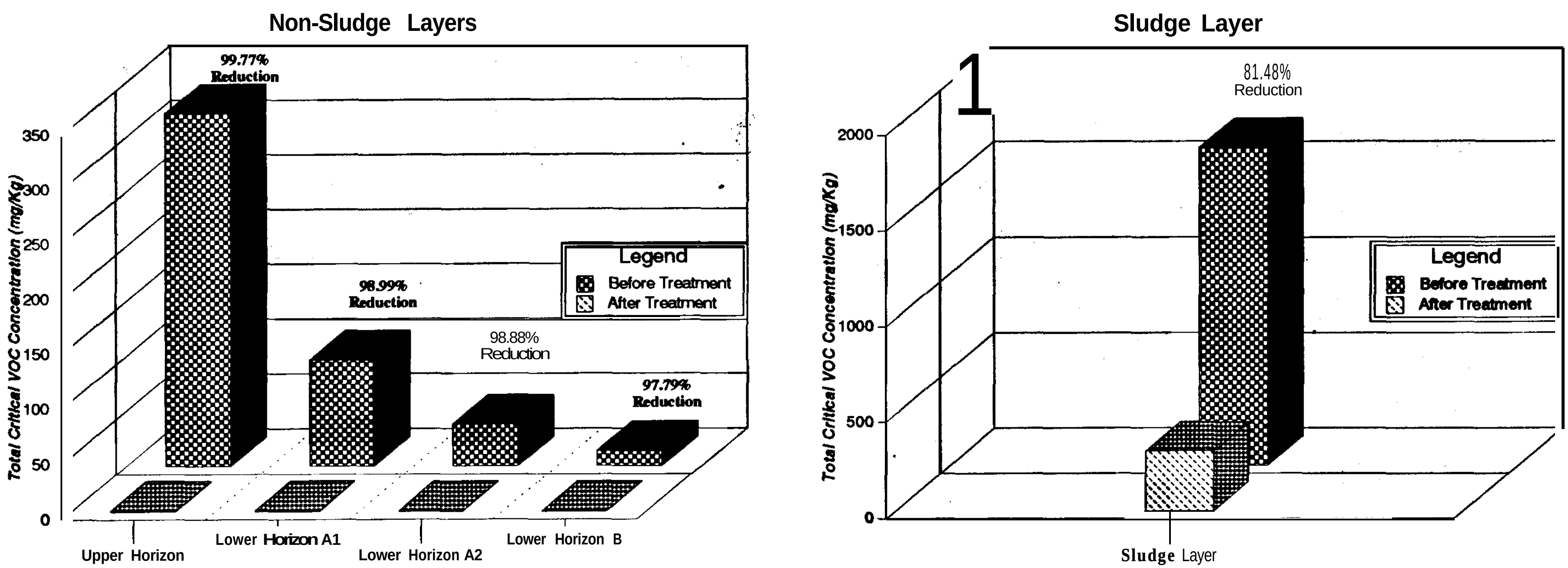


Figure 4-5 **Percent Reduction as a Function of Initial VOC Concentration**

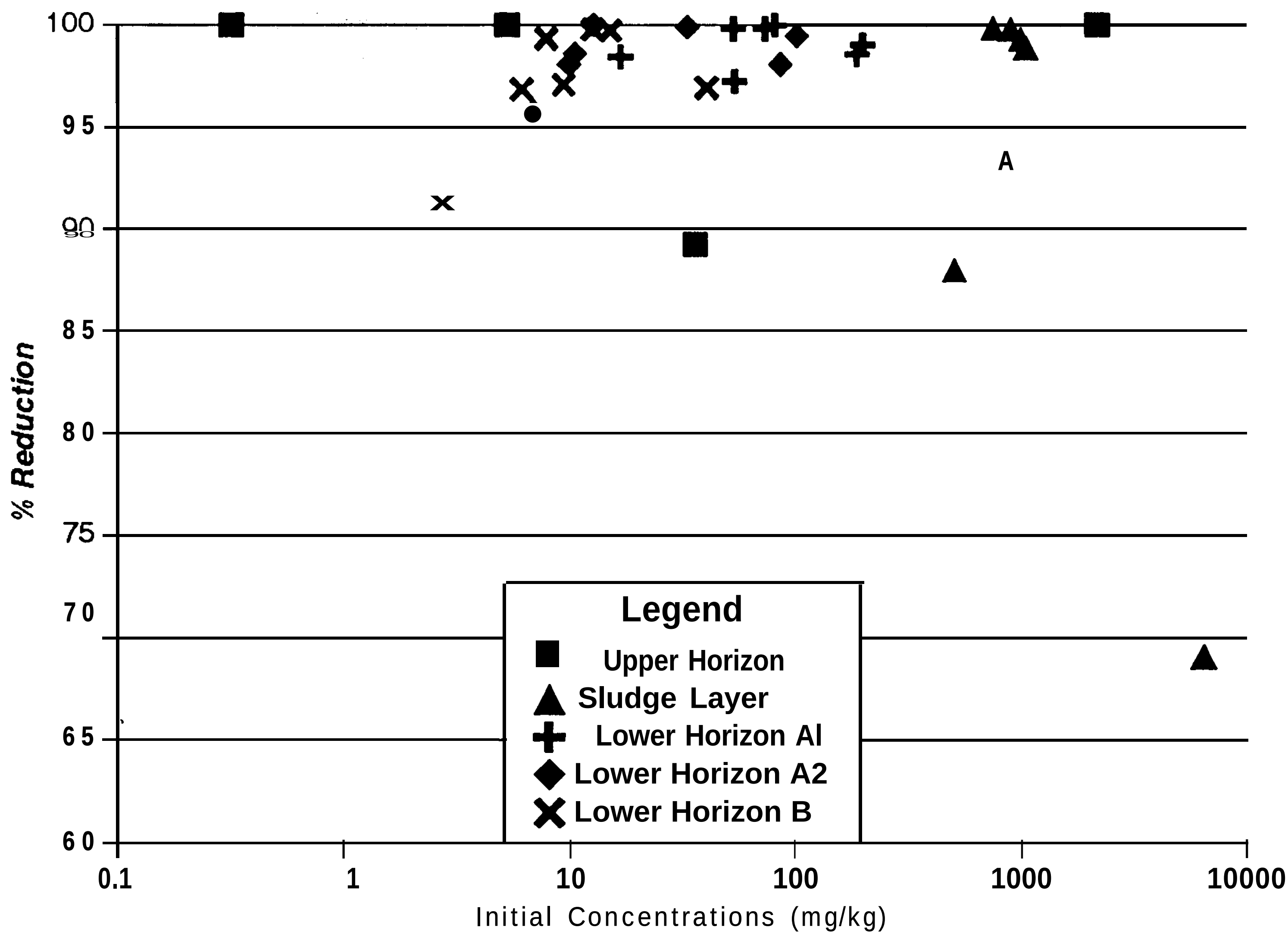


Figure 4-6(a)

Pre-Treatment Contaminant Map: Entire Vadose Zone

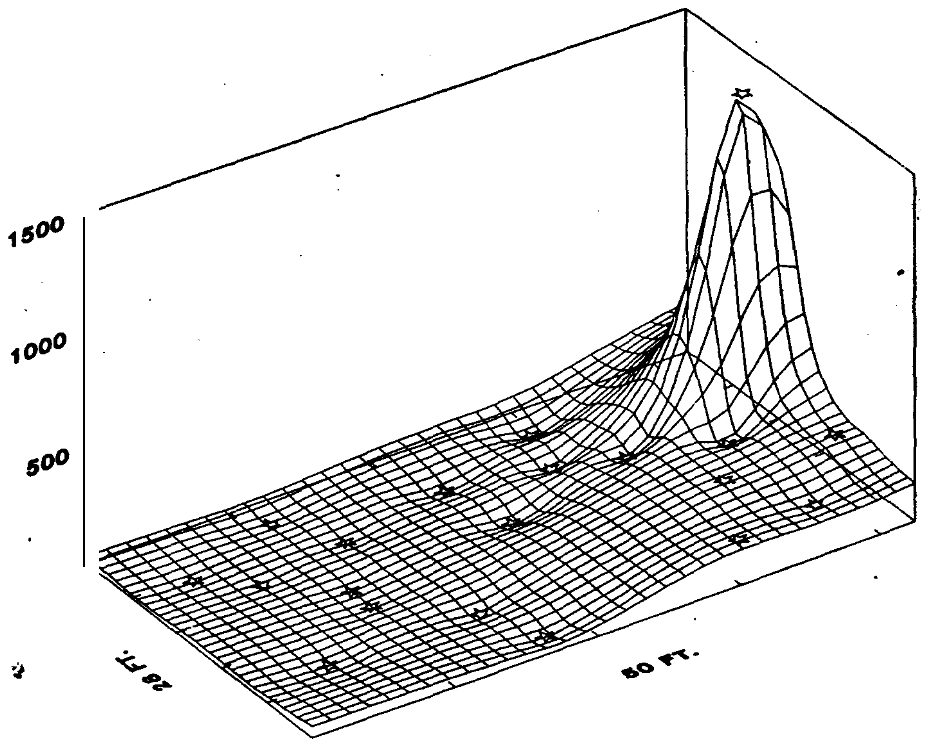


Figure 4-6(b)

Post-Treatment Contaminant Map: Entire Vadose Zone

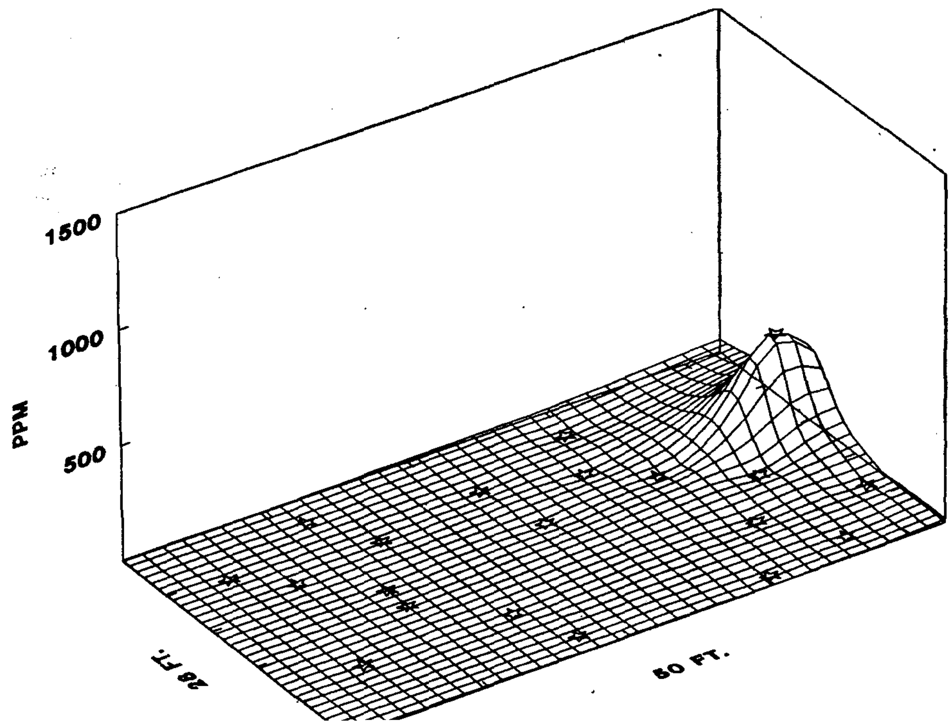


Figure 4-7(a)

Pre-Treatment Contaminant Map: Upper Horizon

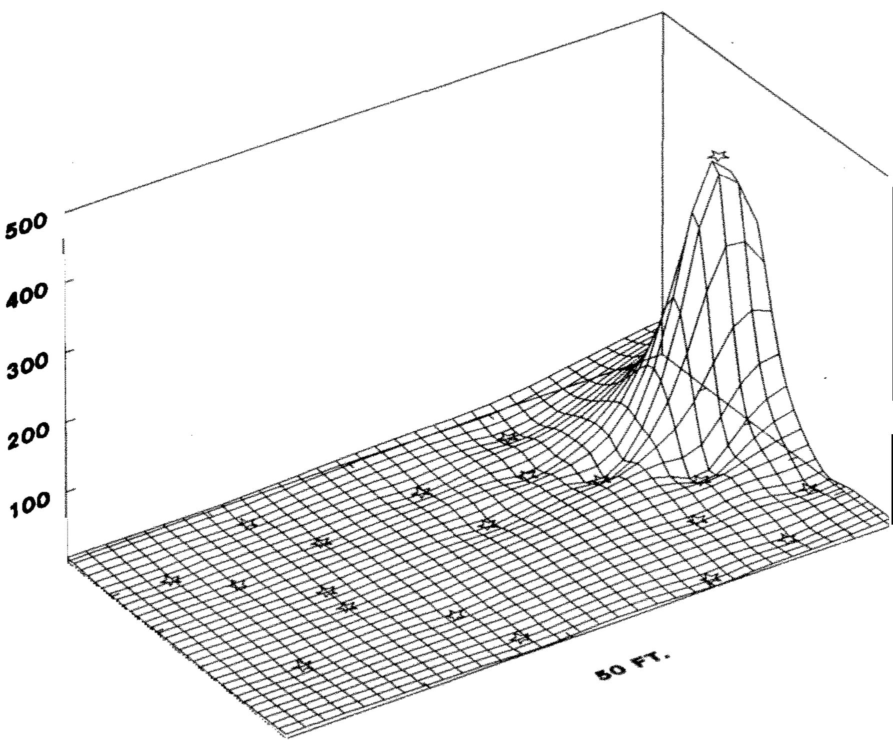


Figure 4-7(b)

Post-Treatment Contaminant Map: Upper Horizon

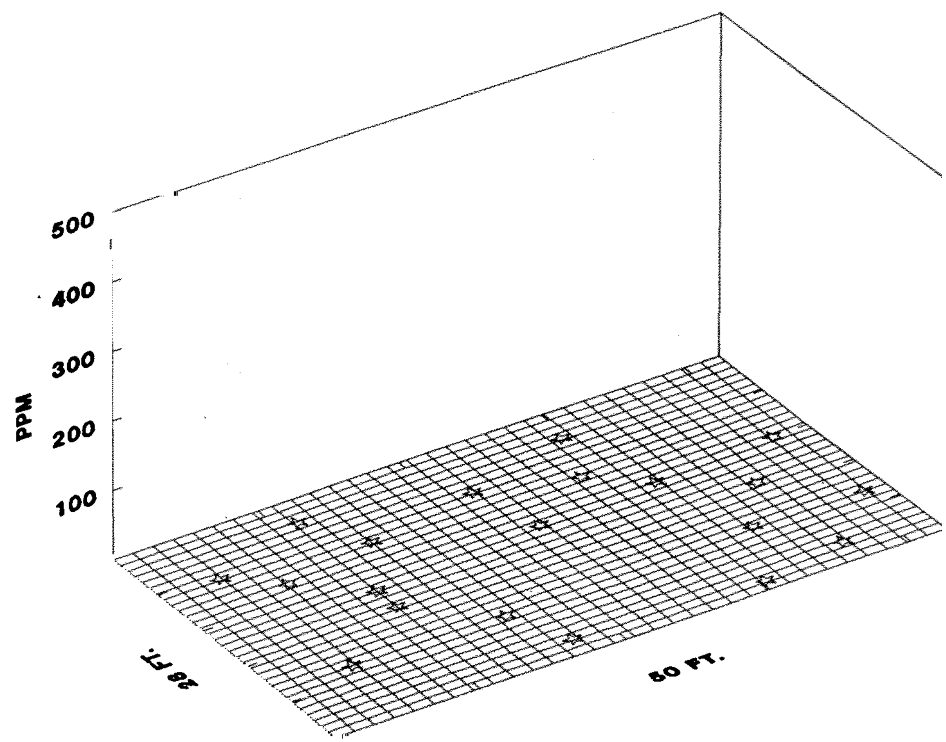


Figure 48(a)

Pre-Treatment Contaminan Map:
Sludge Layer

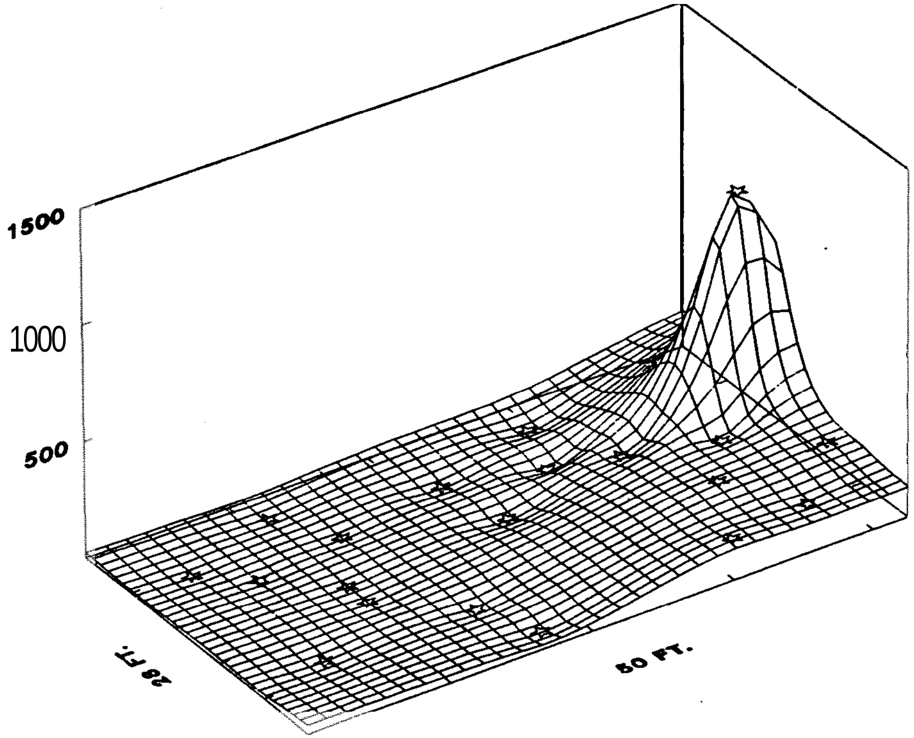


Figure 48(b)

Post-Treatment Contaminant Map:
Sludge Layer

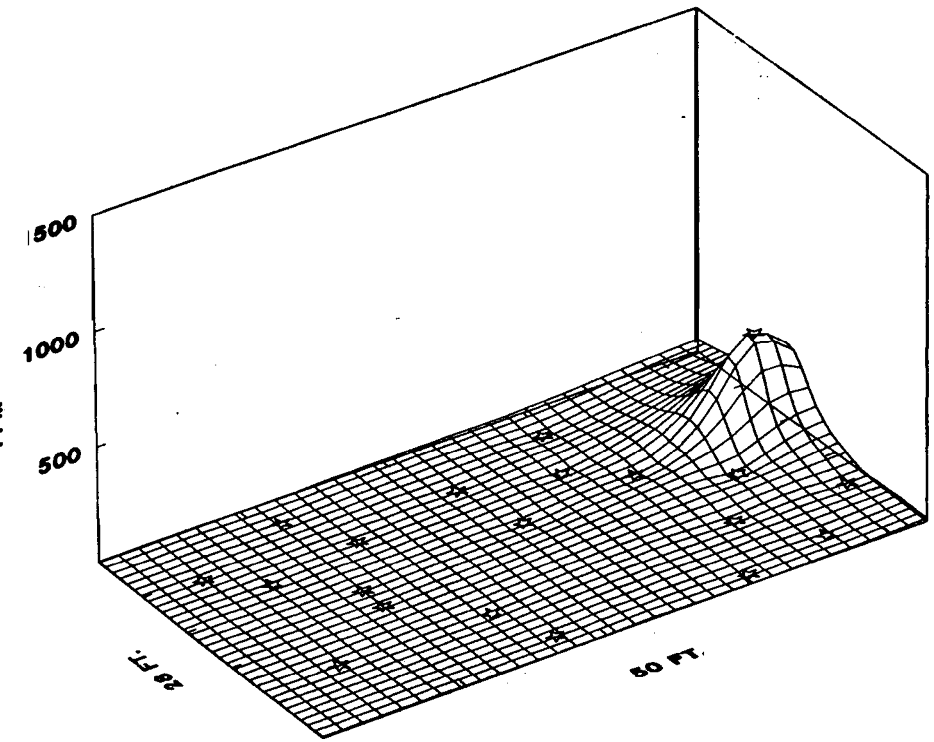


Figure 4-9(a)

Pre-Treatment Contaminant Map: Lower Horizon A

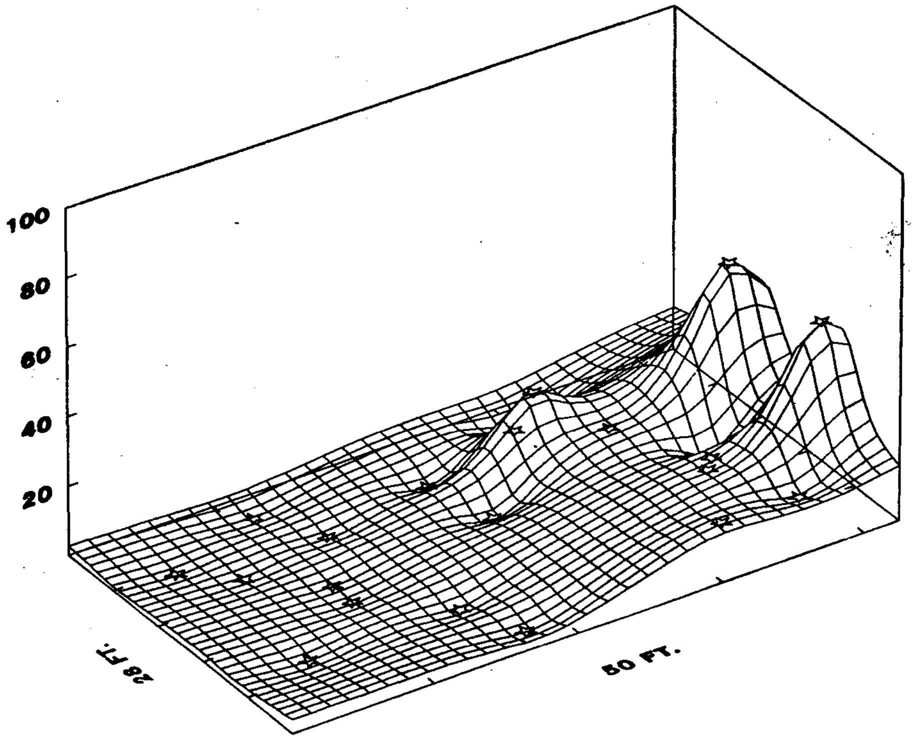


Figure 4-9(b)

Post-Treatment Contaminant Map: Lower Horizon A

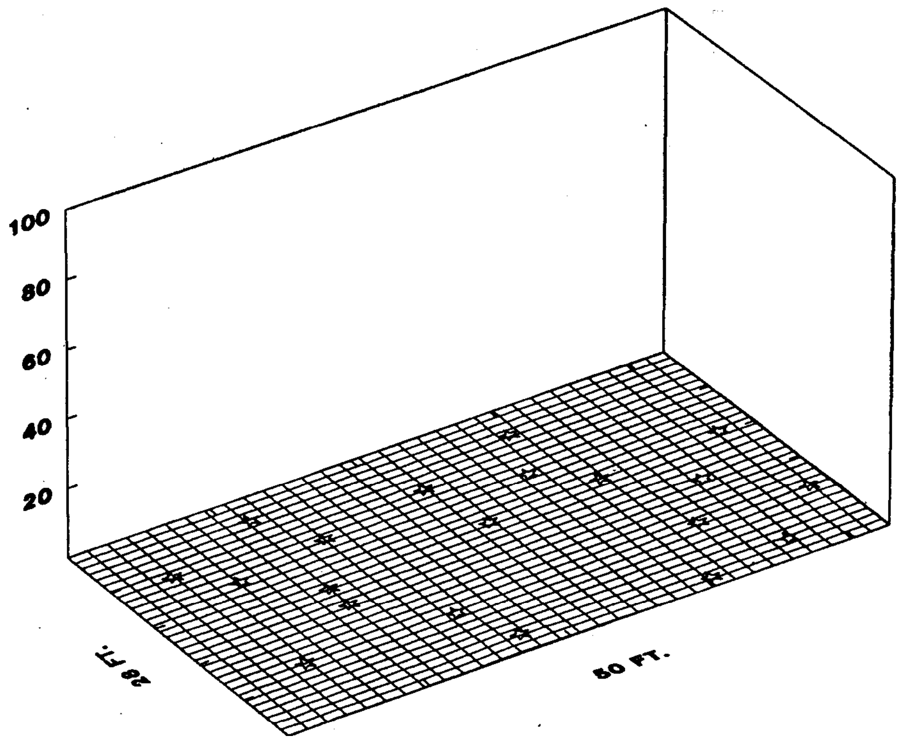


Figure 4-10(a)

Pre-Treatment Contaminant Map: Lower Horizon B

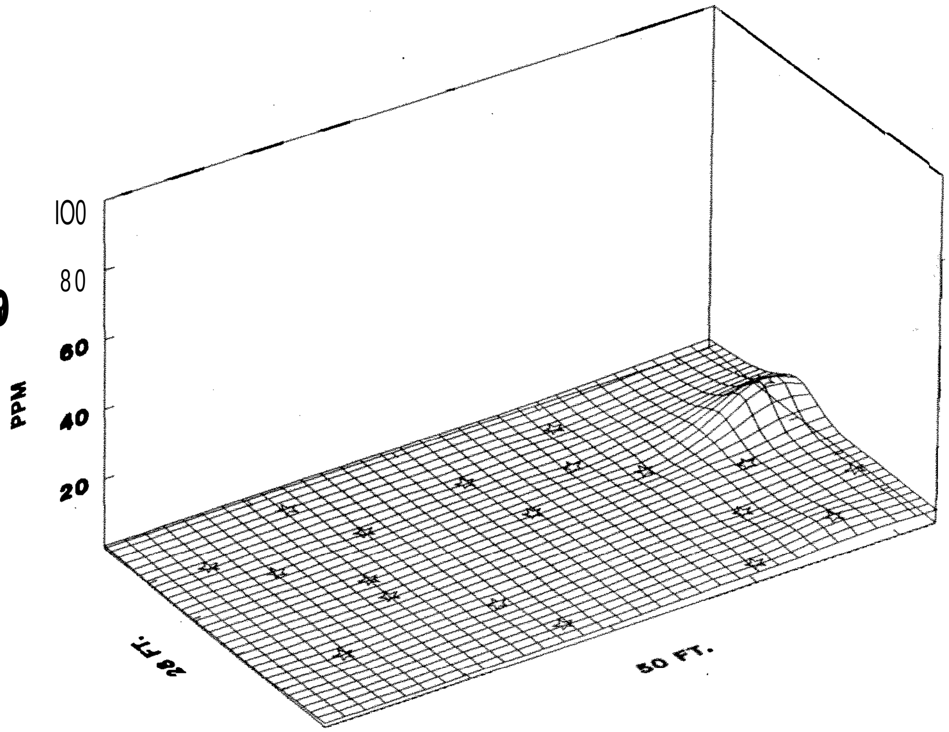


Figure 4-10(b)

Post-Treatment Contaminant Map: Lower Horizon B

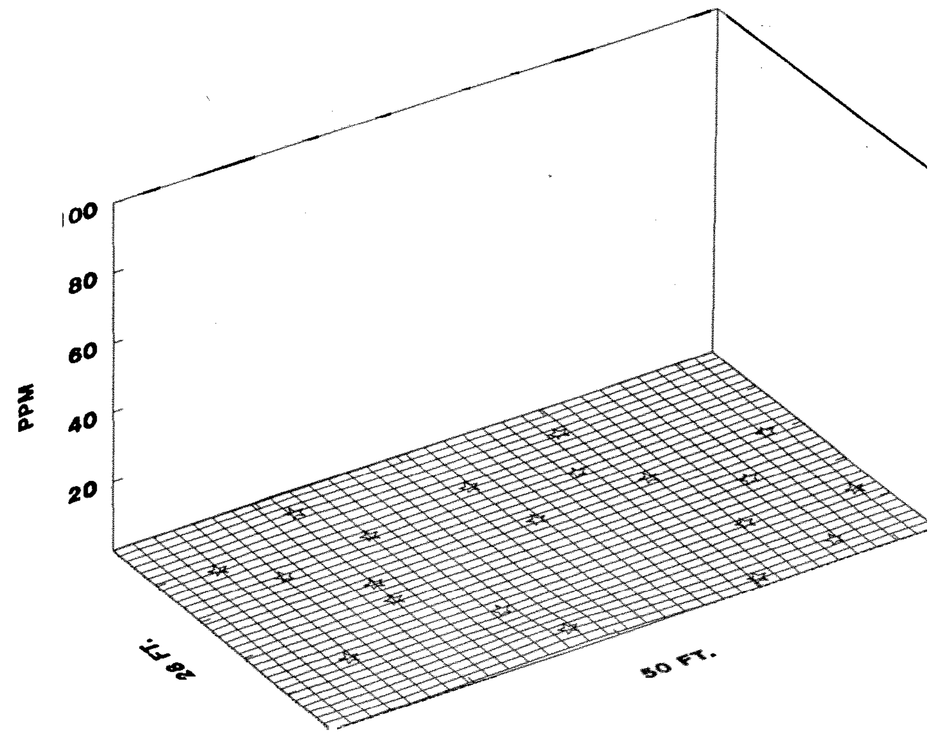


TABLE 4-2
SUMMARY OF THE REDUCTIONS OF INDIVIDUAL CRITICAL VOCs WITHIN ZONE 1 VADOSE SOILS ("HOT ZONE")

CRITICAL VOCs	SUM OF THE WEIGHTED MEAN CONCENTRATION (mg/kg)		% REDUCTION
	PRETREATMENT SAMPLING	POST-TREATMENT SAMPLING	
Benzene	0.01	0.00	*
Toluene	92.84	14.42	84.47%
Ethylbenzene	37.41	6.06	83.81%
Xylenes	205.50	45.28	77.97%
1,1-Dichloroethene	0.01	0.00	*
Trichloroethene	0.36	0.00	*
Tetrachloroethene	5.37	0.44	91.81%

*** A meaningful % reduction can not be provided due to low Pretreatment concentrations**

Figure 4-11 Magnitude of Reduction of Individual Critical vocs

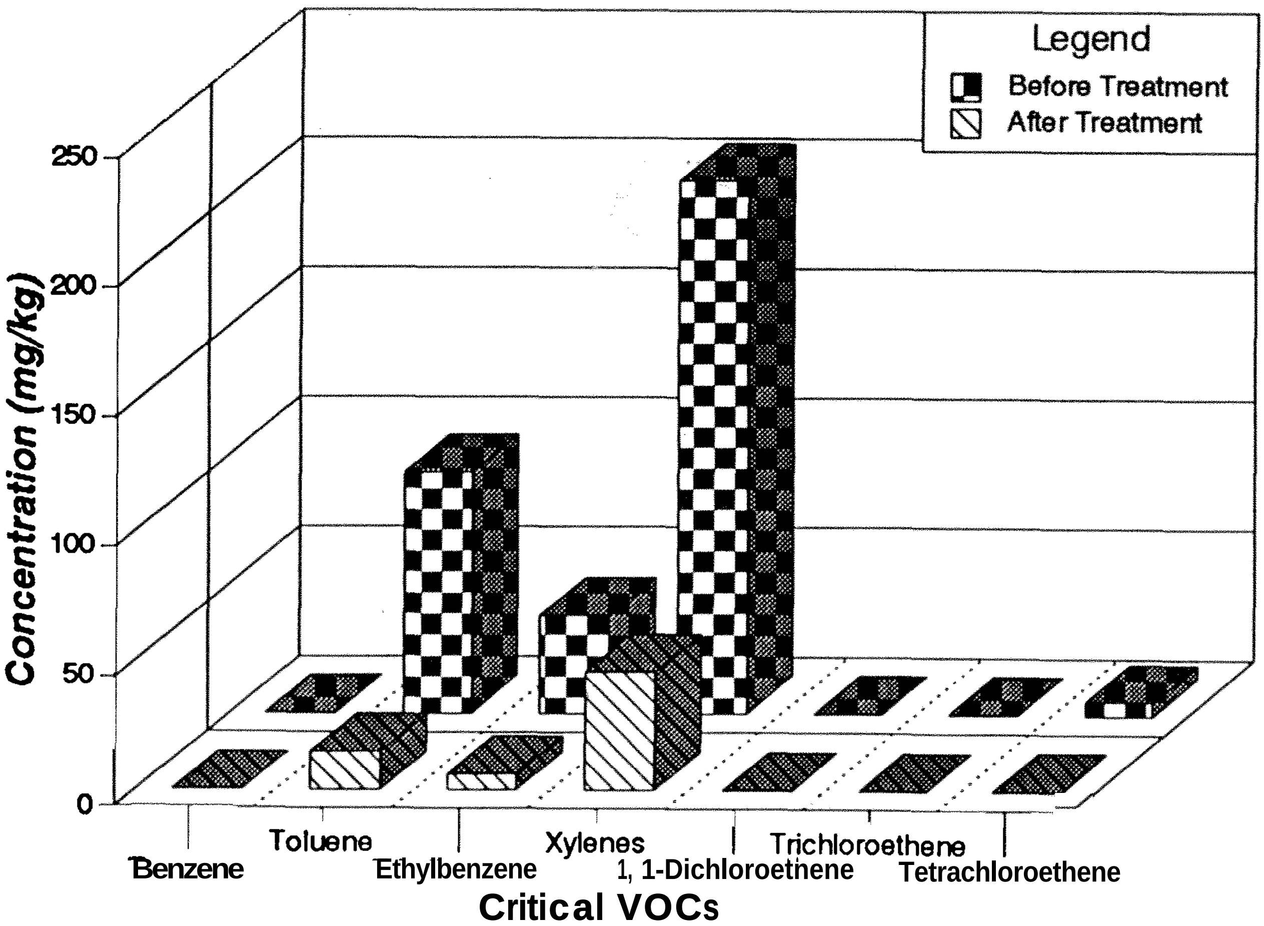
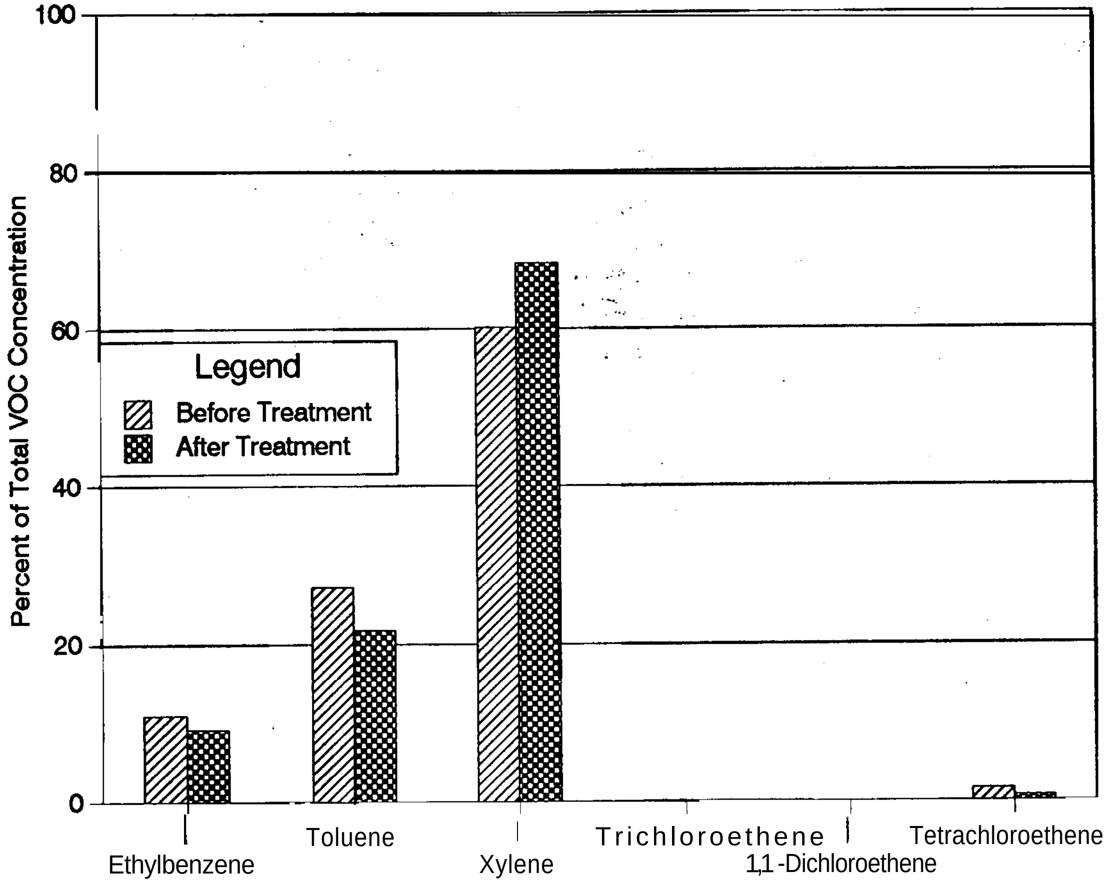


Figure 4-12 Relative Distribution of Individual Soil VOCs Before and After Treatment



Benzene Represented 0% of Total Critical Concentration in the Soils

halogenated VOCs are present in higher concentrations than the halogenated VOCs. Xylene is the most prevalent compound, comprising approximately 60% of the VOCs both before and after treatment, followed by toluene, ethylbenzene, and tetrachloroethene (Figure 4-11). Figure 4-12 also illustrates that the relative distribution of volatile components in the soil is similar before and after the treatment, indicating that the technology does not selectively remove or destroy one component over another.

4.4.4 Effect of the SVVS on VOCs in the Saturated Soil and Groundwater Within the Treatment Plot

In addition to evaluating the SVVS performance in reducing contamination in vadose zone soils of the treatment plot, the technology was evaluated for its ability to effect remediation of groundwater and saturated soil within the physical boundaries of the treatment plot. Except for 1,l- dichloroethene, detected at 12 μg/kg during the first round of groundwater sampling in December of 1992, all remaining sampling events conducted as part of the Demonstration did not yield any detectable levels of contamination from this well. These results stand in contrast to the results obtained during Predemonstration sampling in July 1992 at the time the well was installed, when PCE (0.63 μg/l), toluene (10 μg/l), ethylbenzene (5.8 μg/l), and total xylenes (23.6 μg/l) were detected. With the possible exception of l,l-dichloroethene, the absence of these contaminants in later groundwater samples can not be directly attributed to removal by the technology, since the technology was not turned on until March 1993, and the contaminants yielded during the Predemonstration round were absent in the "Baseline" round conducted in December 1992. The data also show that the SVVS did not merely transfer contaminants from the vadose zone to the groundwater, but removed them from the affected matrix entirely.

Contaminant reduction in saturated zone soils was comparable to trends observed in the vadose zone horizons. Levels of contamination measured during Pretreatment sampling are of similar magnitude to those measured in the less contaminated vadose horizons, with xylenes, toluene and ethylbenzene being the major components. A comparison of the weighted sums of saturated zone VOC contamination before and after treatment reveals that a 99.35% reduction was achieved after one year of treatment. These weighted concentrations of the sum of the seven critical VOCs prior to treatment and after treatment were 37.88 mg/kg and 0.24 mg/kg, respectively. Although the developer did not make any specific claims pertaining to expected removals in the saturated zone, the reductions that were achieved were comparable to those observed in vadose zone horizons, which greatly exceeded the developer's claim of a 30% reduction.

4.4.5 Effect of the SVVS on VOCs in the Groundwater Outside of the Treatment Plot

The impact of the technology on groundwater outside the treatment plot was also evaluated. Four monitoring wells from the existing Electra-Voice monitoring well network were selected for this purpose.

Based upon the position and distance of these wells relative to the treatment plot, coupled with the fact that only one well consistently showed appreciable levels of aromatic hydrocarbon contamination, few conclusions can be drawn on the effectiveness of the SVVS technology on groundwater outside the treatment plot. Although there is little doubt that the dry well is the source of the contaminants found in this well, contamination, based upon field observation during the demonstration, is most likely due to localized infiltration of surface water runoff from the dry well area, rather than groundwater migration. It is interesting to note, however, that contaminant levels showed a decreasing trend over the last six months of SVVS operation. Whether this is due to seasonal factors controlling run-off, or is a reflection of the reduction observed in the upper horizon and sludge layer (both likely sources for contaminants migrating via the surface water pathway), is uncertain.

4.4.6 Impact of Soil Conditions on the SVVS

During Pretreatment and Post-Treatment soil sampling, samples were collected for various other parameters that might inhibit or promote the system's effectiveness. Many of these parameters were collected at the request of the operator to assess the availability of nutrients for in-situ bioremediation. The operator's analysis of pretreatment nutrient availability, which was based on a comparison of the mean concentrations of ammonia, nitrate and total kjeldahl nitrogen suggests that nitrogen is associated predominantly with organic material in the form of biomass. The operator concluded that even before the SVVS was turned on, viable microbial populations existed in the dry well area soils. Other nutrients, such as phosphorus and sulfur, were also measured in vadose zone soils of the treatment plot. The operator conducted an evaluation of the subsurface nutrient requirements necessary to sustain bacterial viability and growth. These were based on the assumption that the total mass of organic contamination in the dry well was biodegradable. Based on the estimated mass of TKN, ammonia and nitrate in treatment plot soils, the operator concluded that there were sufficient quantities of nitrogen available to metabolize the total mass of contamination. The same conclusions were drawn for phosphorus.

According to the operator, macronutrients including calcium, potassium and sodium occur in vadose zone soils at concentrations that favor microbial growth and viability. Iron and magnesium levels are elevated above background values as a result of leaching from buried metal and other debris within the fill that comprises the upper 20 feet of the site.

4.4.7 Extracted Vapor Assessment

The extracted off-gas vapor stream was periodically monitored and characterized to assess the contribution of Soil Vapor Extraction (SVE) processes in the SVVS. Figure 4-13 shows the flow rate of the vapor stream and the mass removal rate of total VOCs over the course of the treatment. These measurements were taken at the inlet to the BEC units. The flow rate of air fluctuated between approximately 60 dscfm and 120 dscfm. The results of this study show typical SVE behavior, suggesting that pore volume exchange rates were higher than what is typically considered optimal for biostimulation.

The mass removal rate of VOCs was high at the beginning of the treatment when soil VOC concentrations were elevated and transfer to the vapor phase occurred easily. As VOC concentrations in the soil decreased over the course of the remediation, the mass removal rate also decreased and stabilized, despite elevated flow rates. This phase of the remediation is characterized by removal rates limited by diffusion of the volatile organics from the solid phase to the air stream. The resulting pattern of soil vapor extraction is characterized as high removal rates during the initial operation of the unit, followed by steadily decreasing removal rates during the middle part of the remediation, ending with low and constant removal rates.

Figure 4-14 compares the relative distribution of VOCs in the extracted air stream at the start of the remediation to the distribution at the end of the remediation. The distributions are similar except for higher contributions of tetrachloroethene, and the absence of ethylbenzene, at the end of the treatment period.

The relative distribution of individual VOCs in the soil is compared to the relative distribution in the extracted air stream, both at the beginning and at the end of the treatment period (Figures 4-12 and

Figure 4-13 Extracted Vapor Stream Over Time

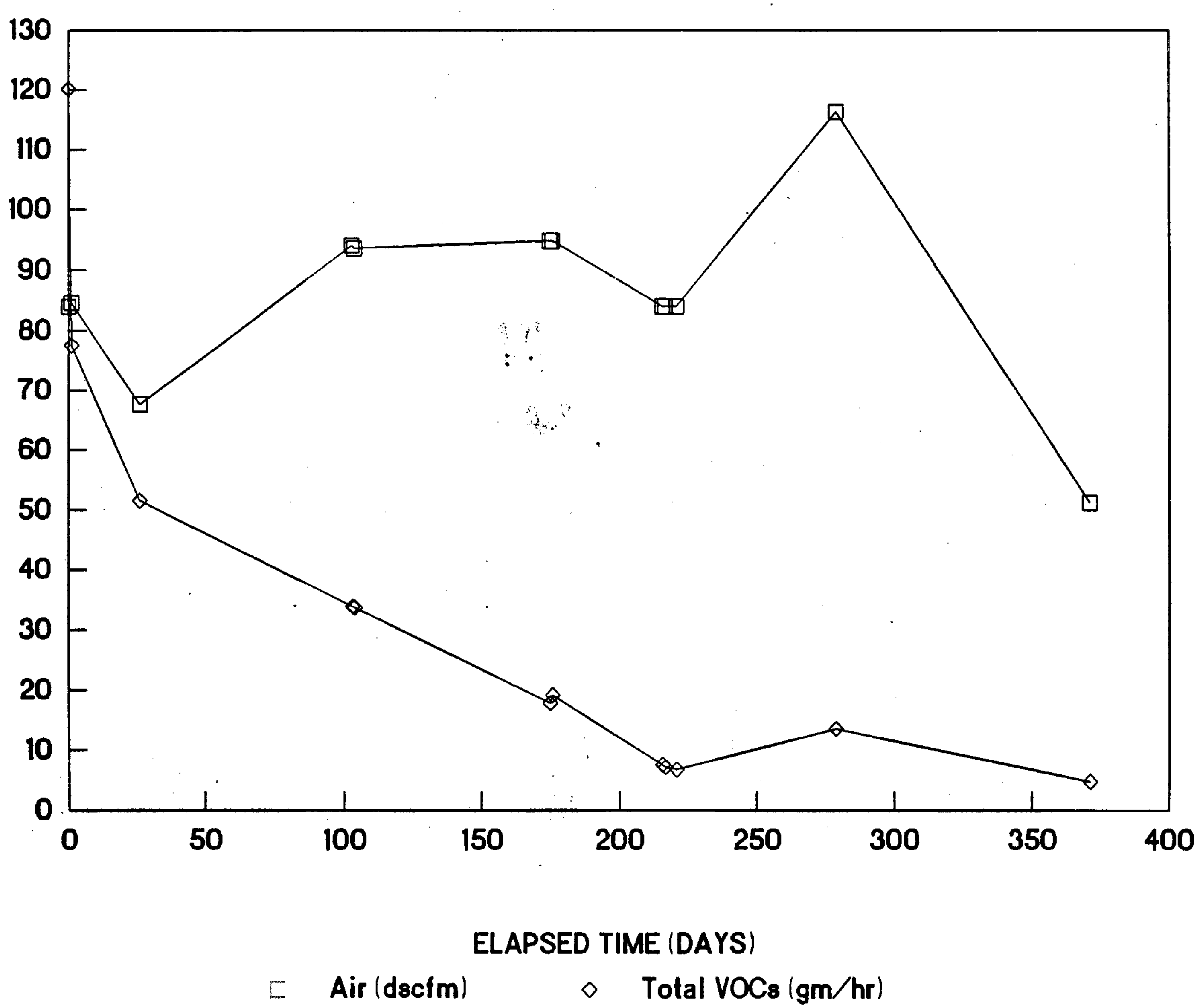
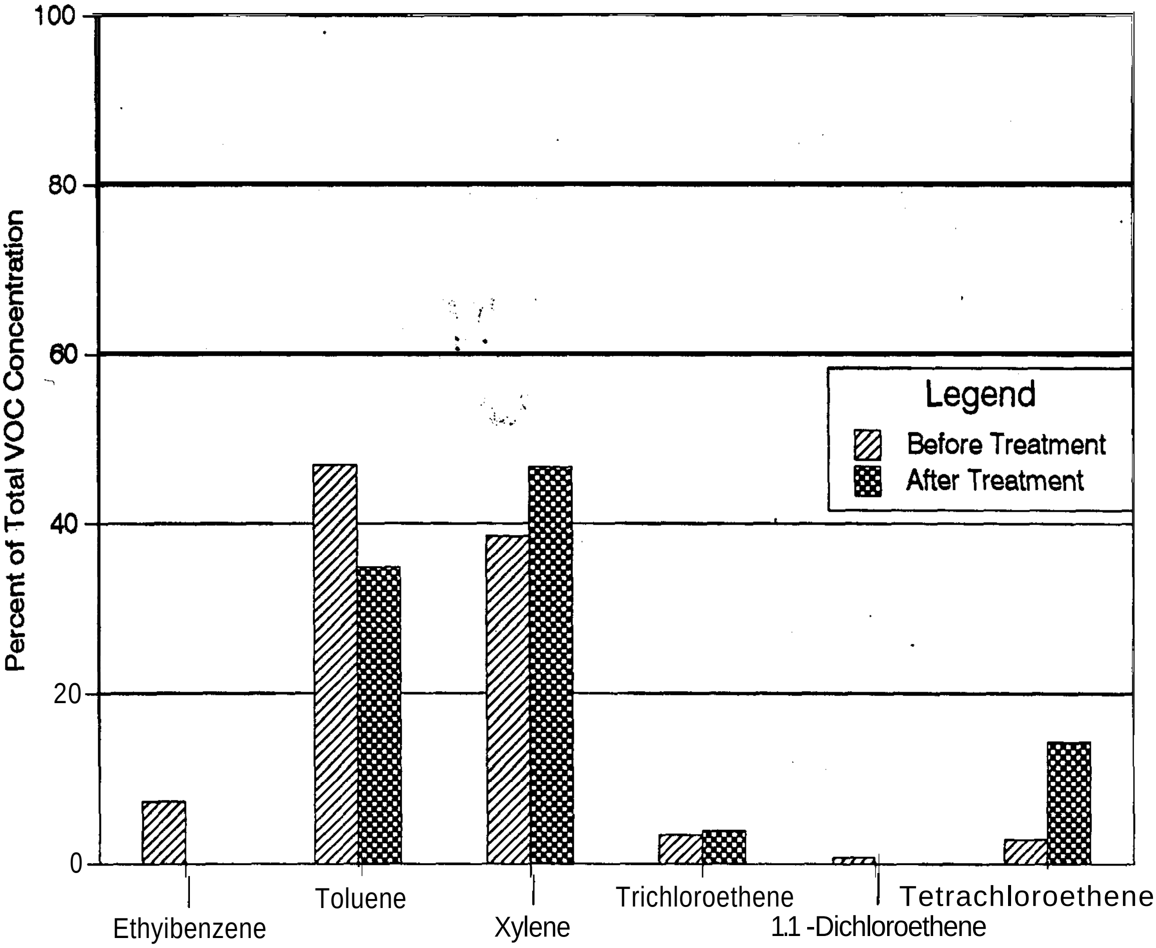


Figure 4-14 Relative Distribution of Individual Air Stream VOCs Before and After Treatment



Benzene Represented 0% of Total Critical Concentration in the Extracted Air Stream

4-14). Relative to the soil, the extracted air stream is enriched in toluene and the halogenated VOCs (trichloroethene, 1,1-dichloroethene, and tetrachloroethene).

4.4.8 Impact of Biodegradation on Contaminant Removal

Developers of the SVVS technology claim that biodegradation is an important remediation mechanism for the destruction of organic contaminants in the sub-surface. Biodegradation dominates during the middle and latter phases of the remediation after the easily stripped-volatiles are removed by SVE. This SITE Demonstration attempted to assess the contribution of biodegradation to the overall reduction of contaminants observed in the subsurface.

The primary measurement tool was the execution of shut-down tests. These shut-down tests monitor changes in sub-surface oxygen and CO_2 following cessation of in-situ ventilation. The magnitude of bacterial processes is directly proportional to the rate of oxygen depletion. Therefore, these shutdown tests measure the presence and magnitude of bacterial processes operative on all organic matter (natural and anthropogenic), and do not directly measure the degradation of specific contaminants. It is generally assumed that stimulation of bacterial processes will result in the accelerated breakdown of biodegradable organic contaminants.

The three shutdown tests were performed at the beginning, middle, and end of the one-year remediation. Oxygen and CO_2 were measured at extraction wells throughout the site, allowing for the determination of biodegradation around the entire site. The results of the shut-down tests provide the following qualitative assessment of the role of biodegradation in the SVVS process.

The magnitude of biodegradation was greatest in the southern portion of the site where contamination was found to be the highest. Within the southern portion of the site, the highest biodegradation rate was encountered from an extraction well located adjacent to a soil boring containing high levels of contaminants. The correlation between high biological activity and contaminant occurrence suggests that the technology was able to stimulate biodegradation of contaminants.

A comparison of the three-shut down tests indicates that biological activity was greatest during the early part of the remediation, moderate in the middle, and lowest at the end. (For a more in-depth analysis, the reader is referred to the TER) This is consistent with the hypothesis that biological activity would decrease as the remediation proceeds due to the reduction of electron acceptors (organics) in the sub-surface. However, the middle shut-down test revealed that the level of bio-activity did not decrease as rapidly as the decrease in hydrocarbons from vapor extraction. This would support the developer's claim that biological processes play an increasingly important role, relative to vapor extraction, as the remediation proceeds.

4.4.9 Performance of BEC Units

The Biological Emission Control (BEC) system could not be evaluated since it was taken out of operation a few months into the Demonstration when the exhaust off-gasses met the State imposed discharge criteria set for operations at the Electra-Voice site. During the brief time the BEC units were in operation, the operator was only observing 30 to 40 percent reductions in system off-gasses. According to the operator greater reductions may have been achieved given sufficient time for the microbes in the BEC units to acclimate to the concentrations in the system's off-gasses. Throughout the remainder of the year long demonstration, only a small percentage of the combined volumetric flow of the air from the extraction wells was routed through the BEC units. This was done to maintain a population of viable microorganisms should off-gas scrubbing become necessary again.

4.4.10 Process Operability and Performance at the Electra-Voice site.

This section summarizes the operability of the process and the overall performance of the SVVS at the Electro-Voice site. It includes discussions about developments and problems encountered, along with the manner in which these items were resolved.

When the SVVS was constructed during July and August of 1992, the intent was to completely encapsulate the location of the former dry well, and the adjoining areas most significantly affected by dry well contamination. Existing data compiled in the Remedial Investigation Report and interviews with facility personnel were used in the conceptual design and the location of the SVVS reactor lines at the Electra-Voice site. The location of SAIC's Predemonstration monitoring well (SAIC MW- 1) marks the spot believed to have been occupied by the former dry well. During the installation of the SVVS a concentration of cobbles and sheets of corrugated metal were encountered while laying down the trench between the middle and western reactor line. This area of buried cobbles and sheet metal, located near SVVS injection well AI-13 and vapor extraction well VE-20, has been inferred to be the former dry well. Contamination trends yielded during Pretreatment sampling would support this, as the bulk of viable vadose zone contamination appeared to be limited to the southern third of the treatment plot, whereas the remainder of the treatment plot was characterized by VOC concentrations at or near their respective detection limits. Based on this information, a significant portion of the treatment system was installed over areas unaffected by the dry well. As a result, the SITE Demonstration Pretreatment data suggest that a substantial area of dry well contamination might lie outside the physical boundaries of the **SVVS®** plot. These revelations did not seem to affect the performance of the SVVS but certainly influenced the operation of the system; northern vapor extraction wells and injection wells were taken out of service after a few months of system operation. Eventually only a small percentage of the wells were operating as a consequence of remedial stresses being shifted to the southern edge of the treatment plot. The inaccurate location of the SVVS process resulted in a somewhat inefficient operation.

Due to special circumstances at the Electra-Voice site, the operator was able to exhaust vacuum extraction off-gas to the atmosphere with little or no treatment. The Electro-Voice site may not be a typical example of SVVS operation, particularly with regard to the handling of extracted vapors. Tighter air emission controls at other sites might necessitate the employment of the BEC units, followed by vapor phase activated carbon, which could increase operational costs by a factor of 1.5 to 2.0. It is likely that additional costs associated with the treatment of system off-gasses would be minimized by controlling vacuum extraction emissions within the regulatory standards, through the adjustment of air injection and vacuum extraction rates. The downside of stepping back injection and extraction rates would be an extension of remediation time; however, the costs associated with extending system operation should be minor in comparison with costs related to activated carbon treatment. The high reduction rates achieved at the Electro-Voice site after one year of treatment might be exceptional, since the air emission standards at the site allowed the SVVS to be operated more in a vapor extraction mode, which favored mass transfer of contaminants to the vapor phase over in-situ biostimulation. This is not to say that in-situ biodegradation did not occur; in fact there is compelling evidence suggesting that it was operative throughout the demonstration, but it was not optimized based on observed vacuum extraction air flows.

4.5 Process Residuals

The actual SVVS process generates few if any residuals. During the winter months as injected and extracted air is cooled, it is possible for several gallons of condensate to accumulate in the lines. Occasionally, enough condensate will accumulate that it will interfere with the operation of the system. When this occurs, the condensate must be siphoned out of the lines. Since the air streams that formed this condensate contained vapor phase contaminants, it is possible that the contaminants partitioned into the condensate. This condensate might therefore be contaminated and require special handling with regard to storage and disposal. Its more likely that the small amounts of condensate that are generated from time to time would simply be used to make up evaporative losses of water in the BEC units, whereby the condensate would be effectively treated in the biofilters.

During system installation a number of process residuals are generated. During the installation of wells and the horizontal emplacement of vacuum extraction and injection lines, potentially contaminated soil cuttings are produced. As a consequence, used PPE and contaminated water from decontamination activities are also generated. All of these items, if found to be hazardous, must be containerized and disposed of as hazardous waste.

SECTION 5
OTHER TECHNOLOGY REQUIREMENTS

5.1 Environmental Regulation Requirements

Federal, state and local regulatory agencies may require permits to be obtained prior to implementing the SVVS process. Most Federal permits will be issued by the authorized state agency. Federal and state requirements may include obtaining a hazardous waste treatment permit or modifying an existing permit regulating these activities on a given site. A permit would be required for storage of contaminated soil in a waste pile for any length of time and for storage in drums on-site for more than **90** days. Air emission permits will probably be required, although such items as site location, off-gas volumetric flow rates and expected VOC concentrations will dictate the need for such a permit. The Air Quality Control Region may also have restrictions on the types of process units and fuels that could be used. Local agencies may have permitting requirements for construction activities (e.g., drilling and excavation), land treatment, and health and safety. In addition, if wastewater is disposed via the sanitary sewer, the local water district effluent limitations and sampling requirements must be met. Finally, state or local regulatory agencies may also establish cleanup standards for the remediation.

At the Electro-Voice site, the operator was required to file an application for an air quality permit with the Michigan DNR prior to receiving permission to release treated off-gases to the atmosphere. The operator was never issued a formal pennit but was required to submit an extensive contaminant dispersal model that calculated anticipated concentrations of any vapor phase contaminants leaving EV property boundaries. Section 2 of this report discusses the environmental regulations that might apply to this technology. Table 2-1 presents a summary of the Federal and state ARARs for the SVVS vapor extraction/air sparging and in-situ bioremediation process.

5.2 Personnel Issues

The S VVS, once operational, can be run in a continuous mode and left unattended for progressively longer periods of time. installation of the SVVS (e.g., laying down reactor lines and drilling/installing vacuum extraction and injection wells) has certain manpower requirements. The number of technicians and construction equipment operators needed for construction of an SVVS depends on the size and design of a particular installation. The manpower requirements for system installation at the Electro-Voice site included two technicians, one field supervisor, and a two-man drill rig crew. The Electro-Voice design consisted of eleven vacuum extraction wells and nine injection wells installed alternately along three individually plumbed rows (i.e., reactor lines). Each reactor line was plumbed to a centrally located vapor control unit (VCU), which housed the pumps, gauging, and emission control equipment. Conditions at the Electra-Voice site required the installation of eight sand chimneys to facilitate vertical circulation through the sludge layer, thereby enhancing volatilization and microbial activity within this zone. At least two technicians are required during system shakedown activities, which are conducted to ensure that there are no air leaks in lines and valves and to optimize remedial stresses in those areas that require it. The shakedown period is considered complete after one week of continuous operation. Once the system is up and running it generally requires minimal attention. System maintenance activities were performed once per week for the first month of operation, once per month for the following three months and then once every three months for the remainder of the demonstration. Additional site visits might be required if analytical and monitoring data suggest that further adjustments to the system are necessary for optimal performance.

Personnel operating the SVVS are trained professionals with extensive knowledge and experience in the complex conditions necessary to enhance the activity of the microbes responsible for VOC destruction. SVVS personnel must have completed the OSHA-mandated 40-hour training course for hazardous waste work, and have an up-to-date refresher certification. Personnel must also be enrolled in a medical surveillance program to ensure that they are fit to perform their duties and to detect any symptoms of exposure to hazardous material.

5.3 Community Acceptance

Potential hazards to the community include exposure to volatile pollutants and other particulate matter released during system installation. These releases can be controlled by watering down the soils prior to any excavation or drilling activities. In the application of any SVE technology, it is imperative that the system include a properly engineered emission capture and treatment system to eliminate the generation of unacceptable fugitive emissions. Noise may also be a factor for neighborhoods in the immediate vicinity of treatment. However, except during system installation when heavy equipment is used, noise associated with the operation of the SVVS is minimal.

SECTION 6
TECHNOLOGY STATUS

This section discusses the experience of the developer/operator in performing treatment using the SVVS vapor extraction/air sparging and in-situ bioremediation process.

6.1 Previous Experience

In addition to the technology demonstration, the SVVS has been employed at over 70 sites involving petroleum hydrocarbon releases over the past five years. The soil and groundwater, including bulk product accumulations, at several of these sites have been cleaned to applicable regulatory standards within this and shorter time frames. The S VVS has also been implemented at sites in New Mexico, North Carolina, South Carolina, Florida, Minnesota, West Virginia, Illinois, Michigan, Pennsylvania, Texas and England. Geological conditions ranged through: elastics with hydraulic permeabilities of 10^{-1} to 10^{-6} cm/sec; caliche deposits; karst terrains, oolitic sands; active marine conditions; glacial deposits; shore deposits and fractured bedrock. In addition to the solvents of this demonstration, the SVVS technology has proven useful on matrices contaminated with BTEX, napthalenes, other PAHs, hydrauhc fluid, #2 fuel oil, jet fuel, diesel, waste oil, kerosene, ethylene dichloride, and ethylene dibromide.

REFERENCES

Newman, W.A. and M.M. Martinson. 1992. "Let Biodegradation Promote In-Situ Soil Venting." ***Remediation,*** Summer 1992. pp. 277-291.

Johnson, P.C. et al. 1990. "A Practical Approach to the Design, Operation, and Monitoring of In Situ Soil-Venting Systems." ***Ground Water Monitoring Review,*** Spring 1990. pp. 159 - 178.

Johnson, P.C., M.W. Kemblowski, and J.D. Colthart. "Quantitative Analysis for the Cleanup of Hydrocarbon-Contaminated Soils by In-Situ Soil Venting." ***Groundwater,*** May 1990. pp. 413-429.

Hinchee, R.E. and R.N. Miller. "Bioventing for In Situ Treatment of Hydrocarbon Contamination." ***Hazardous Materials Control,*** September 1990. pp. 30-34.

King Communications Group. 1994. "Billings and Associates Pioneer Air Sparging." ***The Bioremediation Report,*** June 1994.

U.S. Environmental Protection Agency. 1993. ***Superfund Innovative Technology Evaluation Program: Technology Profiles;*** Sixth Edition. EPA/540/R-93/526. U.S. Environmental Protection Agency. Office of Research and Development. Washington, D.C.

U.S. Environmental Protection Agency. 1991. "Feasibility Study Report: Electra-Voice Inc. Site." WA 37-5PE8. ***Remedial Activities at Uncontrolled Hazardous Waste Sites in Region V.*** U.S. Environmental Protection Agency. Washington, D.C.

U.S. Environmental Protection Agency. 1992. ***Record of Decision Summary: Electra-Voice Site.*** U.S. Environmental Protection Agency, Region V. Chicago, Illinois.

Science Applications International Corporation. 1992. ***Subsurface Volatilization and Ventilation System™ Quality Assurance Project Plan,*** Second Revision. Science Applications International Corporation, Hackensack, New Jersey.

Hinchee, R.E. and SK. Ong. 1992. "A Rapid In Situ Test for Measuring Aerobic Biodegradation Rates of Hydrocarbons in Soil." ***Journal of the Air and Waste Management Association.***

Michigan Department of Natural Resources. 1994. ***Guidance Document: Verification of Soil Remediation, Revision l.*** Michigan Department of Natural Resources. Environmental Response Division. Waste Management Division.

Michigan Department of Natural Resources. 1994. MERA ***Operational Memorandum #8, Revision 3 -- Type B Criteria Rules.*** Michigan Department of Natural Resources. Environmental Response Division, February 1994.

Michigan Department of Natural Resources. 1994. ***Addendum to MERA Operational Memorandum #8, Revision 3 -- Type B Criteria Rules.*** Michigan Department of Natural Resources. Environmental Response Division. June 1994.

REFERENCES (Continued)

Science Applications International Corporation. 1994. ***Site Technology Capsule: Subsurface Volatilization and Ventilation System™ (SVVS™)***. Science Applications International Corporation. Hackensack, New Jersey.

Fishbeck, Thompson, Carr & Huber. 1990. ***Final Remedial Investigation Reportfor Electro-Voice, Inc.*** Fishbeck, Thompson, Carr & Huber. Ada, Michigan.

Halliburton NUS Environmental Corporation. 1992. ***SVVS™ Bioremediation and Demonstration: EPA/Electro-Voice Site.*** Halliburton NUS Corporation. Environmental Technologies Group. Lansing, Michigan.

Mayotte, T. J. 1993. ***A Perspective on the Benefits of the Subsurface Volatilization and Ventilation System™ for Promoting Rapid and Cost-Effective Remediation of Volatile Organic Contamination in the Subsurface.*** Brown & Root Environmental. Holt, Michigan.

Halliburton NUS Environmental Corporation. 1992. ***SVVS™ SITE Demonstration Work Plan.*** Halliburton NUS Corporation. Environmental Technologies Group. Lansing, Michigan.

Brown & Root Environmental. 1993. ***An Evaluation of SVVS™ Performance at the Electra-Voice Site in Buchanan, Michigan.*** Brown & Root Environmental. Lansing, Michigan.

Ecology and Environment, Inc. 1991. ***Supplemental Risk Assessment for the Electro- Voice Site, Buchanan, Michigan.*** Ecology and Environment, Inc. Lancaster, New York.

U.S. Environmental Protection Agency. 1993. ***Remediation Technologies Screening Matrix and Reference Guide, Version I***. EPA 542-B-93-005. U.S. Environmental Protection Agency. Office of Solid Waste and Emergency Response. Technology Innovation Office. Washington, D.C.

Walpole, R.E. and R.H. Myers. 1978. ***Probability and Statistics for Engineers and Scientists,*** Second Edition. Macmillan Publishing Co., Inc. New York.

APPENDIX A
VENDOR'S CLAIMS

This appendix was generated and written solely by Brown & Root Environmental. The statements presented herein represent the vendor's point of view and summarize the claims made by the vendor, Brown & Root Environmental, regarding their SVVS process. Publication herein does not represent the EPA's approval or endorsement of the statements made in this section; the EPA's point of view is discussed in the body of this report.

A.1 INTRODUCTION

It has always been the goal to clean up sites contaminated with volatile organic compounds (VOCs) and semi-volatile organics (SVOCs). Recently, however, there has been increased pressure to implement and complete remediation of contaminated sites in a more timely fashion. Brown & Root Environmental is addressing this challenge in many ways. One method is through the application of the patented Subsurface Volatilization and Ventilation System (S VVS), an integrated process for the remediation of volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) in soil and groundwater.

SVVS takes advantage of liquid to gas equilibrium partitioning, or mass transfer, through the injection of air into the saturated and/or vadose zones below the impacted subsurface materials, and the evacuation of vapors from vertical wells or horizontal lines positioned at shallower depths. This circulation of air allows VOCs and, to a lesser extend, SVOCs to be stripped from the groundwater, soil, and residual soil moisture due to their relatively low aqueous solubilities and high vapor pressures. More importantly, however, the circulation of air increases dissolved oxygen concentrations in the saturated zone, as well as soil moisture in the capillary fringe and vadose zones. The increase in dissolved oxygen concentration serves to stimulate indigenous microbial activity, thereby enhancing and accelerating bioremediation of organic compounds. Therefore, SVVS may be considered primarily a bioremediation technology, which includes the added benefit of inducing contaminant mass transfer and vapor withdrawal through the air circulation process.

An integrated treatment technology such as SVVS, which addresses contamination present in all four phases (liquid product, dissolved, soil moisture and vapor), has many advantages over systems which address only one or two phases of subsurface contamination. When a treatment system is designed to concentrate remediation in only one phase of contamination (such as groundwater), the remaining phases of contamination will continue to be impacted by the phase which is being addressed. For example, pump-and-treat system applications focus on remediation of groundwater, while contamination present in vadose zone soils may continue to act as a source. This transfer between phases accounts for contaminant rebound during remediation. However, if all phases of contamination are addressed simultaneously, as in the case of SVVS, remediation occurs faster, and without the problems and lengthened remedial duration associated with contaminant rebound.

Using S VVS, the combination of mass transfer and enhanced bioremediation is quicker than bioremediation alone, and the total quantities of VOCs that may need additional treatment are lower, than vapor extraction technologies alone. The vapor extraction component destroys the easily-strippable VOC contaminants while the bioremediation component targets the less volatile, more recalcitrant organics. As a result, the integrated S VVS process can treat contaminants that would normally not be remediated by vapor extraction alone (such as chemicals with lower volatility and/or chemicals that are tightly sorbed).

A.2 S VVS® Applications

SVVS can be applied in most situations where subsurface VOC contamination is present. The primary limiting factors, as in any remediation system, are soil typeand the contamination present. To determine the effectiveness of SVVS at a particular site, treatability testing is required to determine optimum design parameters for the system. These parameters include, but are not limited to, the permeability of subsurface materials and the characterization of the microbes that occur naturally in subsurface materials. Microbial specific parameters that are helpful also include the optimum nutrient formulation (nitrogen, phosphorus, trace metals, etc.) for each respective microbial consortia, environmental conditions (pH, temperature, hardness, alkalinity, etc.), and the possible toxicity/inhibitoty effects of the organics on the respective biological cultures.

A.2.1 Geology/Hydrology Requirements

One of the most important factors affecting SVVS system design is the permeability of the soil. SVVS is most effective in fine to medium sand deposits with permeabilities greater than 1.0×10^{-6} centimeters/second (cm/sec). However, SVVS also has been applied with positive results at sites having deposits of silts and clays with permeabilities less than 1.0×10^{-6} cm/sec. Coarse-textured soils that have a higher permeability allow higher flow with the same induced vacuum than soils with lower permeabilities. In general, contamination that is present in formations with low permeabilities (silts and clays) is remediated more slowly. This can be controlled by adjusting certain design parameters such as system pump size and well spacing.

A.2.2 Contaminants Amenable to the SVVS® Process

The contaminants to be remediated must either have a vapor pressure suitable for mass transfer or must be amenable to bioremediation. For dilute concentrations in water, Henry's Law Constants serve as a measure for determining if the contaminant can be effectively stripped. Compounds with Henry's Law Constants greater than 2×10^{-3} atm-m^3/mol are considered to be amenable to SVVS. Removal effkiencies for these contaminants generally range from 50 percent to greater than 90 percent.

In-situ microbes destroy the contaminants by converting them into carbon dioxide, water, and cell mass instead of merely transferring the contaminants to a different media. Bioremediation also will remediate contaminants that normally would not be remediated by vapor extraction alone (such as chemicals with lower volatility and/or chemicals that are tightly sorbed). With conventional aerobic biological treatment systems, organic destruction efficiencies can reach in excess of 99% if properly operated.

The SVVS process has been employed at over 70 sites of petroleum hydrocarbon compound releases over the past five years. The soil and groundwater, including bulk product accumulations, at several of these sites have been cleaned to applicable regulatory standards. In addition, SVVS has also been implemented to remediate halogenated aliphatic compounds in the subsurface. The system has effectively treated low concentrations of halogenated aliphatic compounds that are dense non-aqueous phase liquids (DNAPLs), including tetrachlorethane and trichloroethene.

For higher concentrations of DNAPLs where free product may have accumulated above less permeable zones, SVVS should also be effective. By creating a containment area through the horizontal and vertical placement of air sparging wells, it may be possible to disperse DNAPL contamination within a controlled area. Dispersing the DNAPL contamination will create low concentration zones that SVVS can effectively remediate. S VVS well placement also can be designed to confine the DNAPL compound to a central area where it can be collected from a recovery well.

A.3 SVVS Design

The design of SVVS allows for flexibility both in terms of system expansion and operation. Because of the simplicity of system construction, and the reserve capacity of air injection and vapor extraction capabilities built into a typical design, the system may be easily expanded. In addition, SVVS systems are operated in a dynamic fashion to provide the most favorable in-situ conditions for the destruction of VOCs by the pertinent indigenous microbes. The system not only allows for the delivery and circulation of air, and therefore oxygen, but also can be modified easily to deliver certain nutrients necessary to optimize microbe viability.

A.4 Implementation

Installation of the SVVS system is flexible. In an effort to minimize costs and disruption of normal facility operations, the installation is often coupled with previously scheduled site remodeling activities. Air injection and vacuum extraction wells and reactor lines are installed in trenches approximately one foot wide and three feet deep, making it possible to place plates over the trenches so that normal site activities can still be performed during SVVS installation. The majority of SVVS installation activities are completed in one to two weeks.

A.5 Operations and Maintenance

Once the system is on-line, SVVS operations and maintenance (O&M) activities are less intensive than with traditional treatment technologies. To optimize the performance of a typical SVVS system, data is collected and adjustments are made once a week for the first three months. This is necessary because during the initial three months significant reductions in subsurface contamination will be observed. In addition to optimizing system operation, regulatory reporting (Air Use Permitting) may require adherence to this rigorous schedule during the initial phase of remediation. In most applications, following the first three months of operation, O&M activities can be reduced to once per month for the duration of the project.

A.6 costs

SVVS is unique because the majority of costs associated with the remediation of a site are related to system installation rather than labor intensive O&M activities. This is largely due to the relatively short remedial duration, which usually ranges from 3 to 5 years.

The most significant costs associated with SVVS are system installation capital costs, such as pumps, the treatment building, and the off-gas treatment system(s). Typical SVVS systems are installed and operated at costs ranging between $100,000 and $250,000. Because of the flexibility of the system, the cost of SVVS expansion is normally no greater than 10% to 20% of a project's total budget.

A.7 Evaluation of SVVS

SVVS is not a cure-all for all sites and situations. However, given suitable conditions, SVVS has been proven to be a fast and effective method for soil and groundwater remediation.

A.7.1 Advantages

SVVS provides rapid, integrated remediation of contaminated soil and groundwater by synergistically combining in-situ bioremediation and direct volatilization of contaminant removal from all affected media (the saturated zone, the capillary fringe, and the vadose zone). SVVS is the most complete system for in-situ restoration of contaminated soil and groundwater, with demonstrated success on more than 70 UST sites.

By removing hydrocarbons simultaneously from all affected phases, SVVS helps solve the problem of groundwater re-contamination often associated with traditional pump and treatment technologies. SVVS remediates the contaminated soil in the saturated zone, capillary fringe, and vadose zone directly, eliminating the sources that might re-contaminate groundwater. In addition, the SVVS process can be applied to a wide variety of sites contaminated with multiple VOCs and SVOCs in varying subsurface conditions. SVVS systems may achieve site closure in significantly less time and at a lower cost than traditional pump and treat and soil vapor extraction methods.

It is an attractive option for effecting rapid cleanup in most subsurface conditions at a significantly reduced cost compared to traditional remediation methods. In addition, **SVVS®** presents a way for industry to minimize liabilities through emphasis on contaminant destruction rather than transferral of VOC mass to another medium.

These facts emphasize that, at a minimum, consideration should be given to **SVVS®** when assessing the technical and economic feasibility of various remedial alternatives for addressing VOC and SVOC contamination in subsurface materials.

A.7.2 Limitations

SVVS® may not be an economically beneficial alternative for some remediation applications. For instance, when remediating small, localized areas of contamination, the system installation capital costs may not be practical. Also, when remediating subsurface materials having low permeabilities, an increased number of wells, larger pump sizes, and longer remedial durations may increase system installation capital costs and O&M costs to the point where it is not an economically beneficial alternative. In situations involving localized contamination and/or subsurface materials with low permeabilities, a detailed cost analyses should be performed.

APPENDIX B

CONVERSIONS

Mass

1 pound (lb) = 0.4536 kg

1 ton = 2,000 lb = 907.18 kg

1 kilogram (kg) = 2.20 lb

Volume

1 cubic inch (in^3) = 5.78E-04 ft^3 = 2.14E-05 yd^3 = 0.0164 L = 1.64E-05 m^3 = 4.33E-03 gal

1 cubic foot (ft^3) = 1,728 in^3 = 0.0370 yd^3 = 28.32 L = 0.0283 m^3 = 7.48 gal

1 cubic yard (yd^3) = 46,656 in^3 = 27 ft^3 = 764.55 L = 0.7646 m^3 = 201.97 gal

1 cubic meter (m^3) = 61,023 in^3 = 35.31 ft^3 = 1.31 yd^3 = 1,000 L = 264.17 gal

1 liter (L) = 61.02 in^3 = 0.0353 ft^3 = 1.30E-03 yd^3 = 1.00E-03 m^3 = 0.2642 gal

1 gallon (gal) = 231 in^3 = 0.1337 ft^3 = 4.95E-03 yd^3 = 3.7854 L = 3.79E-03 m^3

Length

1 inch (in) = 0.0833 ft = 0.0278 yd = 0.0254 m

1 foot (ft) = 12 in = 0.3333 yd = 0.3048 m

1 yard (yd) = 36 in = 3 ft = 0.9144 m

1 meter (m) = 39.37 in = 3.28 ft = 1.09 yd

Temperature

1 degree Fahrenheit (*F) = 0.5556°C [x°C=0.5556 * (y°F-32)]

1 degree Celsius (*C) = 1.8°F [x°F=1.8 * (y°C)+32]

Pressure

1 pound per square inch (psi) = 27.71 in H_20 = 6894.76 Pa

1 inch of water (in H_20) = 0.0361 psi = 248.80 Pa

1 Pascal (Pa) = 1.45E-04 psi = 4.02E-03 in H_20

Viscosity

1 poise = .1 kg/m-sec = 2.09E-03 lb/ft-sec

1 kg/m-sec = 10.00 poise = 2.09E-03 lb/ft-sec

1 lb/ft-sec = 478.70 kg/m-sec

Rate

1 lb/hr = 2.20 kg/hr

1 kg/hr = 0.4536 lb/hr

*U.S. GOVERNMENT PRINTING OFFICE: 1995-653-292